DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH
GEOLOGICAL SURVEY OF GREAT BRITAIN

GEOLOGY
OF
BEN NEVIS
AND
GLEN COE

SECOND EDITION

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1960

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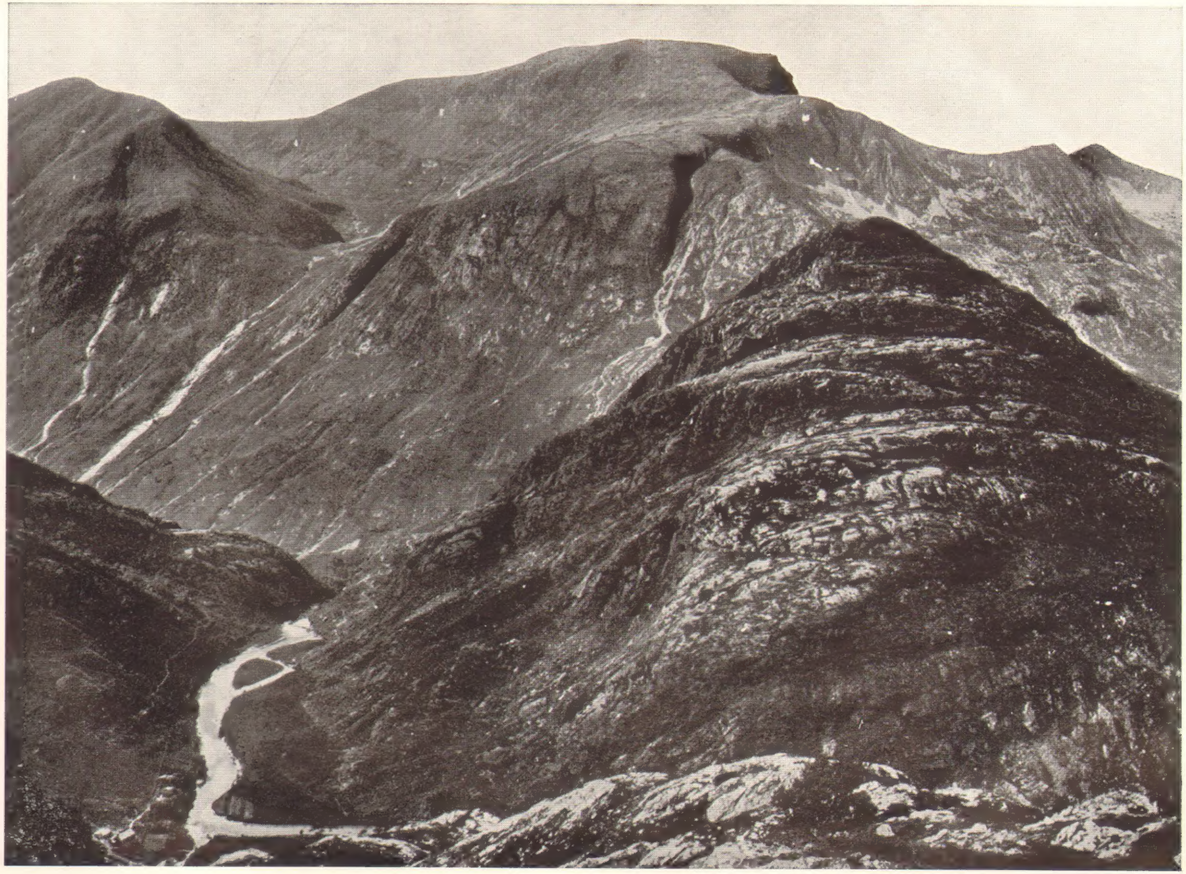

Ben Nevis with hanging corrie, and River Nevis disappearing into Nevis Gorge

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

MEMOIRS OF THE GEOLOGICAL SURVEY
SCOTLAND

The Geology of Ben Nevis and Glen Coe and the Surrounding Country

(EXPLANATION OF SHEET 53)

By
E. B. Bailey, B.A. and H. B. Maufe, M.A.

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G. W. Grabham, M.A. ; H. Kynaston, B.A. ;
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SECOND (REVISED) EDITION
By
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with Economic Chapter by
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IN DEFENS

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1960

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PREFACE TO FIRST EDITION

THE region described in this memoir is situated in one of the most rugged parts of Scotland. Ben Nevis (4406 ft) is the highest mountain in Great Britain, and several peaks in the eastern part of the area rise to heights of 3000 ft and over. Between them run glens correspondingly deep and often remarkably picturesque, the most famous being Glen Coe, Glen Nevis, and Glen Etive. The great hollow of Loch Linnhe, forming the continuation of the long line of Loch Lochy and Loch Ness, cuts obliquely across the region from south-west to north-east, and admits the sea far inland. For boldness of relief and for opportunities for studying the origin of geographical features this tract is not surpassed in Britain.

The mapping was begun in 1895, and was carried on under the superintendence of Dr. B. N. Peach till 1903, and thereafter under Mr. C. T. Clough as District Geologist. Mr. J. S. Grant Wilson mapped most of the ground north-west of Loch Linnhe, and on the south-west side of that loch he took in hand considerable areas around Fort William, Onich, Ballachulish, Appin, and Glen Creran. Mr. E. B. Bailey, in addition to a small area in Glen Tarbert, mapped much of the eastern portion of the Sheet as far south as Glen Coe, and subsequently, after an interpretation of the geological structure of the district had been suggested by Mr. Maufe and himself, he re-examined most of the ground between Fort William and Appin. Mr. Maufe mapped Ben Nevis and the greater part of the volcanic rocks of Glen Coe, and a small district south of Glen Tarbert. The southern and south-eastern margins of the Sheet were surveyed by Mr. Kynaston; Mr. Wright undertook the examination of the area east of Kinlochleven; Mr. Grabham, the upper part of Glen Etive; Mr. Clough mapped a small area near Dalness; and Dr. Peach collaborated in the survey of Glen Coe in addition to mapping a limited tract near Glen Gour.

The memoir has been edited and mainly written by Mr. Bailey.

The geology is both varied and complex. Upon a groundwork of crystalline schists an extensive covering of lavas was spread in the time of the Lower Old Red Sandstone, but of this covering parts only have survived denudation in Ben Nevis and in the mountains around Glen Coe. At this time also great intrusions of granite rose, and igneous dykes were injected in vast numbers, more especially in the two "swarms" of Ben Nevis and Glen Etive. Some suggestions offered with regard to their origin may prove to be applicable to dyke-swarms in other regions. The superficial, hypabyssal, and plutonic rocks of Lower Old Red Sandstone age form a suite of unusual perfection. Their description is accompanied by analyses of representative rock-types. In Tertiary times several dykes were injected along cracks having a general north-westerly direction.

No less interesting are the phenomena of contact-alteration induced within the aureoles surrounding the plutonic masses. Schists, lavas, and even earlier members of the intrusions all display in varying degrees the changes due to heating in the neighbourhood of the molten rocks.

The geological structure of the area presents some remarkable features, the existence of which was not suspected in this part of Scotland. As the detailed six-inch survey progressed, it became apparent that some of the complicated sequences and repetitions of rock-types in the schists were capable of interpretation if it could be shown that the schists had not only been folded but that the folds had been prostrated and pushed forward horizontally in a recumbent position. The suggestion, first made by Mr. Maufe, was proved by Mr. Bailey to be applicable to a considerable region between Ben Nevis and Appin, and the existence of recumbent folds, accompanied by slides and fold faults, was announced in papers laid before the Geological Society of London. The cauldron-subsidences or sunken volcanic areas of Glen Coe and Ben Nevis, surrounded by ring-dykes, form another feature of unusual interest in the tectonics of this region. In Glen Coe especially the subsidence can be connected with the peripheral upwelling of magma. The character of the cauldron subsidences was described before the Geological Society of London by Messrs. Clough, Maufe, and Bailey.

The glaciation at its maximum was effected by an ice-sheet by which the whole district was smothered, and which was advancing towards the Atlantic Ocean from an ice-parting situated just outside, or possibly passing within the north-eastern part of the area included in the map. The course of the ice was determined mainly by the great hollow of Linnhe, and at a later stage almost every glen was occupied by a valley-glacier.

Thanks are due to the Councils of the Geological Society of London and of the Geologists' Association for permission to reproduce several illustrations relating to the district which have appeared in the publications of those Societies.

A. STRAHAN
Director

Geological Survey Office,
28 Jermyn Street,
London.
16th April, 1915.

PREFACE TO SECOND EDITION

THE district of Ben Nevis and Glen Coe is much visited by British and Overseas geologists, either individually or in parties organised by scientific societies and universities. It has three main attractions: (1) recumbent folds and slides affecting its metamorphic sediments; (2) cauldron-subsidences associated with igneous centres at Ben Nevis and Glen Coe; and (3) problems attaching to its through and hanging valley systems. There is also marked contrast of grade of regional metamorphism shown at the present level of erosion by schists within and without the cauldron-subsidences of Ben Nevis and Glen Coe, and even stronger contrast on the two sides of Loch Linnhe. In both cases the phenomenon is dependent upon faulting. At the cauldron-subsidences, as H. B. Maufe recognised, it follows from vertical displacement of metamorphic zones through some thousands of feet. At Loch Linnhe, W. Q. Kennedy attributes it to horizontal displacement along the Great Glen Fault amounting to 65 miles; but in this case most of the relevant evidence lies outside of Sheet 53.

The setting is appropriate. Thus the stratigraphical succession in the schists is, in most of the district, very clear and simple; while the igneous rocks, associated in varying degrees of intimacy with the cauldron-subsidences, afford the most representative display of plutonic, hypabyssal and volcanic products of Lower Old Red Sandstone age to be found anywhere in Scotland; and finally the topography which calls for interpretation is extremely impressive from the scenic point of view and has proved of great industrial value as a factor in the development of hydro-electricity.

Two main discoveries have been made since the first edition of this memoir appeared. At that time the recumbent folds of the district had been traced, for the most part in the forms which are accepted today; but it had not been found possible to decide which of the two orders presented by the folded rocks was normal, and which inverted. Three young geologists from abroad, T. Vogt, S. Buckstaff and O. N. Rove supplied the key to this puzzle in 1924, basing on interpretation of current-bedding often wonderfully preserved in quartzite members of the succession. The second discovery stems from the first. As stated above the stratigraphical succession in the schists is clear in most of the district; but this does not hold in the Loch Leven area, where, when the first edition was published, it was a matter of discussion as to whether there were three stratigraphically distinct quartzites in the succession, or only one repeated by folding. The former view had been advanced by R. G. Carruthers in 1913, and has now been confirmed with the help of additional evidence derived from current-bedding. An associated advance is that anyone today visiting Kinlochleven can easily satisfy himself of the existence of an immense inversion, for practically all the current-bedding of the locality is upside down.

E. B. Bailey, who edited and mainly wrote the first edition, has shared in subsequent research, and has edited the present edition. So far as possible the essential authorship of various sections is indicated in the usual fashion by appending initials, even where adjustments with acknowledgement have been made. One new author has been introduced, T. R. M. Lawrie, who has prepared the economic chapter.

The 1st Edition of the one-inch to one mile geological map, Sheet 53 (Glen Coe), was published in 1921, and the 2nd Edition in 1940. The 3rd Edition, with profile sections to illustrate tectonics and cauldron subsidence, appeared in 1948 and is still on sale.

As before thanks are given to the Councils of the Geological Society and of the Geologists' Association for permission to reproduce several illustrations relating to the district, which have appeared in their publications.

W. J. PUGH
Director

Geological Survey Office,
Exhibition Road,
London, S.W.7.
27th July, 1960.

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[1] Reference number of photograph in the Geological Survey Scottish collection.

THE GEOLOGY OF BEN NEVIS AND GLEN COE, AND THE SURROUNDING COUNTRY

CHAPTER I

INTRODUCTION

PLACE names are often difficult to decipher on the Geological Survey one-inch-to-the-mile map, Sheet 53. Accordingly all those that are used in this memoir are included in the Memoir index along with their *National Grid References*, the interpretation of which is explained at the bottom of the 3rd Edition map of 1948[1]. Contours have suffered even more than place names in the preparation of Sheet 53 ; while two very important, comparatively recent roads, one along the south shore of Loch Leven to Kinlochleven, the other through Glen Coe, have not been inserted. The Seventh Series edition of the Ordnance Survey one-inch map remedies these failings. Sheet 46 of this Seventh Series covers the western part of Sheet 53 (Geological), as far as a N.-S. line about a mile east of Fort William, and Sheet 47 covers the remainder. Together these Seventh Series sheets extend well beyond the boundaries of Geological Sheet 53. There is also an Ordnance Survey one-inch Tourist Map of Lorn and Lochaber, compiled from these and adjacent Seventh Series Sheets, which covers the whole area of Sheet 53 (Geological). Attention may also be directed to Fig. 22, a contoured locality map of the Glen Coe district (p. 136).

Another difficulty arises in regard to the name *Ballachulish*, employed repeatedly in the sequel. The Gaelic means " distributed township of the narrows". Thus Sheet 53 (Geological) and Ordnance Survey 7th Series Sheet 46 show North Ballachulish (north of Loch Leven) as close to the ferry, and South Ballachulish (south of Loch Leven) as extending eastwards from the ferry for a couple of miles to the River Laroch. Here a bridge separates a village into West and East Laroch. In common speech these together are known as Ballachulish village served by Ballachulish railway station. Whenever Ballachulish village is mentioned in this memoir it is in the sense of West and East Laroch ; but Ballachulish House and Ballachulish Hotel are situated just south of the ferry and are served by Ballachulish Ferry railway station ; and what is known as the Ballachulish Pluton is a granodiorite complex that reaches southwards for five miles from where they stand.

Sheet 53 (Geol.) is divided into two parts by Loch Linnhe running north-east and south-west. The portion of the district lying south-east of Loch Linnhe, and north of Loch Leven, and of the River Leven which drains into the latter, belongs to Inverness-shire. All the rest falls to Argyllshire.

The main centres of population are Fort William, East and West Laroch (or Ballachulish), Onich, Kinlochleven, Clovulin, and Portnacroish (" Appin " on the railway). Cultivation is restricted to the immediate vicinity of the coast-line and, even there, is extremely local. A considerable strip of sheep ground, half a dozen miles wide, flanks Loch Linnhe on the south-east, and cattle have been locally re-introduced as in Cona Glen ; but most of the country is given over to deer. Glen Coe is owned by the National Trust for Scotland.

---

[1] National Grid References with similar interpretation are also given in the index for several localities outside sheet 53.

The slate quarries of Ballachulish have been worked for generations, and have a great name in Scotland. Other mineral products include granite, quartzite and dolomite. The rise of Kinlochleven is a notable development of the last fifty years. An important aluminium factory has been established here at the head of Loch Leven in the heart of the wild, romantic scenery of the district " 'twixt Ben Nevis and Glen Coe." It derives its water-power from the great Blackwater Reservoir which has been constructed in the valley of the River Leven, for the most part to the east of the border of the present map.

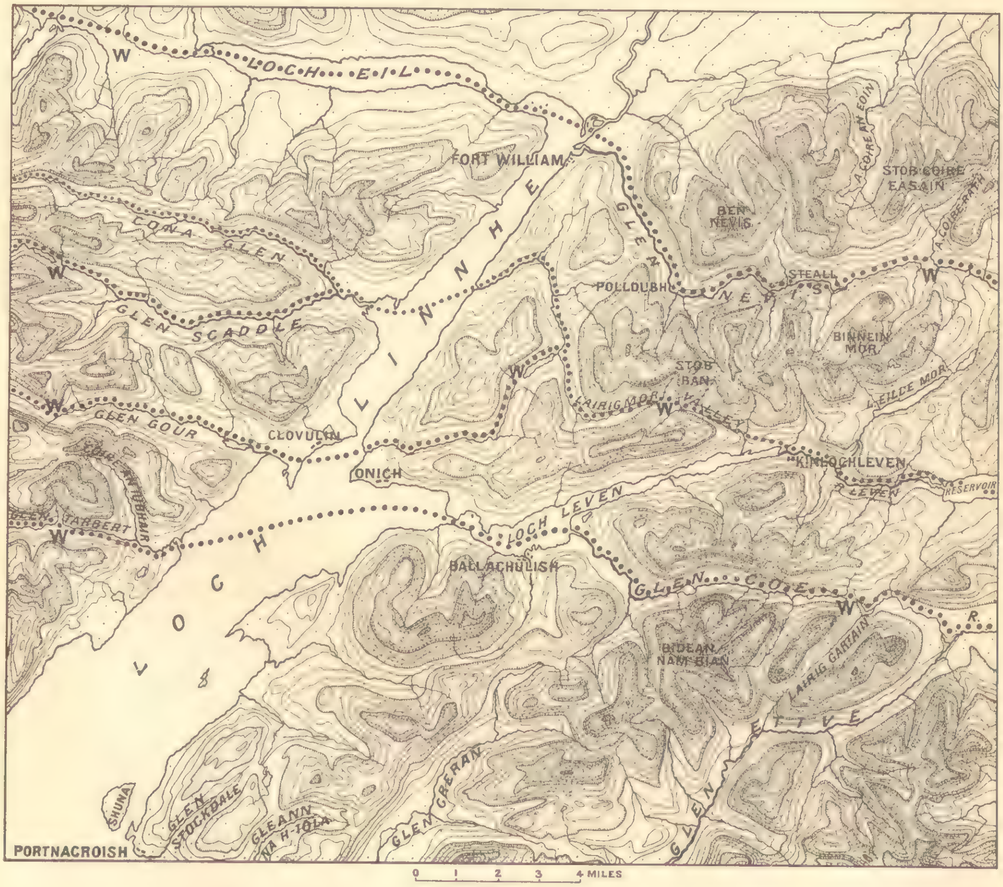

FIG. 1. Map of inferred original Tertiary drainage system (shown in heavy dots)

Shatter-belts guide Loch Linnhe, Loch Leven and Lairig Gartain.
Contour-interval 250 ft, with change of ornament every thousand feet.
W, Secondary Watersheds. R, west end of Rannoch Moor

PHYSIOGRAPHY

The following account substantially reproduces what was published in the first edition of this memoir, which itself expanded a preliminary statement in the Proceedings of the Geologists' Association (Bailey 1911). The stock of interpretative ideas from which selection was made, coming fifty years ago, was very much the same as it is today. Some of the conclusions reached were debatable then and are so still. On p. 13 attention will be directed to contributions that have appeared in the interval.

The district is a much dissected portion of the main Highland plateau (*cf.* Geikie 1901, chap. vii), with a summit-level east of Loch Linnhe of about 3000 ft. Ben Nevis, 4406 ft high, and several other massifs, such as Bidean nam Bian, 3766 ft high, south of Glen Coe, overlook the neighbouring ridges and appear to be features inherited from an earlier geographical cycle. West of Loch Linnhe the general level for the dissected plateau is some 500 ft lower than on the east. It is very commonly supposed that the main 3000-ft summit surface corresponds approximately with the land surface upon which the present drainage system was initiated, or else with the upper limit of hard Highland rocks beneath such a land surface. Both hypotheses may be very far from true.

In the vicinity of Loch Linnhe the eastern segment of the main high-level plateau merges southwards into the much lower plateau of Lorne, to which the island of Shuna and neighbouring portions of the mainland may reasonably be referred. There is no sharp boundary here between the two plateau regions such as is encountered along the Pass of Brander at the foot of Ben Cruachan (Sheet 45, Geol.).

Archibald Geikie has repeatedly drawn attention to the fact that the drainage system traversing the high-level plateau is of later date than the Tertiary volcanic outbursts of the Hebrides. The present district furnishes a good illustration of this, for many of its valleys, such as Glen Tarbert, have been cut across Tertiary basalt dykes. On the other hand, Bremner, as we shall presently see, argues that since the Hebridean volcanoes were terrestrial there must have been contemporaneous and presumably even earlier rivers.

Structure-guided Through-Valleys.—Through-valleys and hanging valleys are strikingly represented in the drainage system. Some of the through-valleys have clearly been determined by the structure or grain of the country ; while others, so far as one can judge, are essentially independent of it. Of the first type the best illustration is the valley of Loch Linnhe, which lies along the shatter-belt[1] of the Great Glen, a continuous feature traversing Scotland from side to side ; another shatter-belt valley is that of Loch Leven and Loch-Eilde Mòr ; and yet another holds the upper part of Loch Etive (Sheet 45, Geol.), and the lower part of Glen Etive, as well as Lairig Gartain, and, north of Glen Coe, Allt Lagan na Féithe.

It must not be imagined, of course, that structurally determined valleys are necessarily through-valleys maintaining their individuality for long distances at a time. In some cases the influence of structure can only be recognised for a comparatively short interval. Thus the river Nevis, above the entrance of Allt Coire na Gabhalach, has been deflected for about a mile along a shatter-belt ; while farther downstream, east of Meall Cumhann, it follows for a rather longer distance a fold which was originally in large part occupied by easily eroded calc-silicate-hornfels. Then again, Glen Etive, in its upper reaches, and several tributary streams of Glen Coe (see Meeting of Three Waters, Pl. VII, p. 139), have been guided by north-east dykes of porphyrite (and porphyry) ; and, in like manner, Glen Stockdale, Gleann na h-Iola, and Glen Creran have been locally compelled to accept the direction of the strike of the schists.

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[1] The term, shatter-belt, is adopted from J. E. Marr, whose Presidential Address, dealing with ' The influence of the geological structure of English Lakeland upon its present features ' (1906, pp. cii—cxxiii), materially assisted in the development of the conceptions set forth in this chapter. Marr, in later years, came to regard glacial erosion as of more importance than when he delivered this address, but many of his conclusions remain unaffected by this change of opinion.

It is impossible to pass without reference an important book by J. W. Gregory, published (1913) since the present chapter, as first written, was almost complete. Gregory's theme is the origin of fiords, and he includes Loch Linnhe and Loch Leven as characteristic examples of the class. His discussion is wide, and embraces the main topics dealt with in this chapter. In many instances his arguments and conclusions agree with those set forth below, and they are illustrated with a wealth of detail drawn from other lands, which gives them an additional value. In one important particular, however, Gregory's treatment differs from that adopted here, for he attributes a more direct share to earth-movement in the shaping of Scotland, especially the West Highland coast-line. A similar interpretation has been advocated for years in connection with the Norwegian fiords by de Geer and other Scandinavian geologists.

The earth-movements to which Gregory appeals are supposed to have accompanied the foundering of the North Atlantic Ocean in late Miocene or early Pliocene times. Some few depressions as the Minch, inside of the Outer Hebrides, and the Midland Valley, south-east of the Highlands,[1] he attributes to trough-faulting. The fiords of the West Highlands he believes originated for the most part as gaping faults and joints, which have been worn into troughs by subaerial and glacial erosion. According to Gregory not only did new faults originate, but old faults moved again. In this connection it is worth quoting from J. Horne's description of the Inverness earthquake of 1901. " A long crack or fissure . . . formed in the middle of the towing-path (of the Caledonian Canal, near Dochgarroch Locks), and could be traced at intervals for a distance of 600 yds. In no place was the fissure more than half an inch wide. The position of the Great Glen fracture laid down on the six-inch field map coincides with the trend of this fissure " (*in* Horne, Hinxman and others 1914, p. 69). Gregory believes that the severance of the original drainage that crossed the line of Loch Linnhe (Fig. 1) was accomplished by Tertiary subsidence on the north-west side of the Great Glen Fault ; as stated above, the Highland Plateau north-west of Loch Linnhe is about 500 ft lower than to the south-east, though the correspondence seems scarcely definite enough to serve as basis for an argument.

While it is impossible to do justice to Gregory's position in a short notice, the following comments may be offered :

(1) Gregory probably somewhat overrates the proportion of structure-guided valleys in the West Highlands.

(2) The main features, apart from straightness, of the structure-guided valleys are reproduced in valleys independent of such guidance.

(3) The shatter-belts which can be examined along the line of certain structure-guided valleys, as at the head of Loch Leven, seem quite sufficient in their nature to locate deep, straight valleys of erosion without assuming gaping fissures.

(4) If such gaping fissures were very commonly developed during movements affecting the West Highlands in Middle Tertiary times, how is it that we never come upon any that have been choked with the gravel and sand of the period ?

(5) A similar conflict of opinion formerly existed concerning the origin of the Zambezi Gorge (Lamplugh 1907, p. 165). Some attributed its zig-zag course to a tectonic rent, but it is now admitted that the gorge is being excavated along intersecting joints which lie latent, so to speak, until the adequate conditions of erosion present themselves. This agrees with the long-accepted interpretation of structure-guided valleys in the West Highlands.

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[1] Gregory, by mistake, ascribed this view to the writer (1913, p. 175).

Independent Through-Valleys.—Through-valleys of the second type, that is independent of structure, are well represented on both sides of Loch Linnhe : on the north-west lie Glen Scaddle, Glen Gour, and Glen Tarbert ; on the south-east, Glen Nevis, the Lairigmòr and River Leven valley, and Glen Coe extended eastwards along the Moor of Rannoch (R. in Fig. 1 ; see also Bailey 1934b, fig. 3).

Two distinct interpretations have been adopted in regard to such through-valleys in the Scottish Highlands. H. M. Cadell (1886), H. J. Mackinder (1907, p. 126), and B. N. Peach and J. Horne (1910, p. 547) regard them as representative of a drainage system which once led continuously across Scotland, more or less from west to east, but is now in large measure broken up into segments owing to the development of subsequent valleys along special lines of weakness. R. S. Tarr (1908), on the other hand, regarded them as a result of glacial erosion. The last-named author summarised his position as follows :

> " The through valley condition, a great aid to travel in glaciated lands, is found in the Alps, in Alaska, in Central New York, and in the Scottish Highlands. It is as characteristic of glaciated lands as are the hanging valley, the steepened slope, and the ' canal ' valley, and, so far as I am aware, is all but unknown in regions which glaciers have never occupied ".

This appeal from glaciated to unglaciated topography, to ascertain such features as have resulted from glacial erosion, is a most encouraging sign of the times. A like comparison was employed many years ago by A. C. Ramsay (1862, p. 201) in relation to rock basins ; the extension of the principle, and its detailed application is, however, mainly due to American geographers such as W. M. Davis (1909) and Tarr. But when attention is paid to the through-valleys of Scotland as a whole, their distribution seems too systematic to admit of a semi-accidental origin connected with glaciation. The evidence points strongly to the alternative conclusion, namely that the majority of them are remnants of a once continuous drainage system. In Fig. 1, expression is given to this alternative interpretation. It may be urged by some that the correspondence of the through valleys on the north-west with those on the south-east of Loch Linnhe, as shown in this figure, is fanciful. Perhaps, but at any rate the principle involved is vindicated in what appears to the writer to be self-evident fashion in two local instances : the first is afforded by the obvious former continuity of Lairigmòr—River Leven drainage, now interrupted by the shatter-guided valley of Loch Leven and Loch-Eilde Mòr ; the second, by the obvious former continuity of Glen Coe—Moor of Rannoch drainage, now interrupted by the dyke-guided valley of Upper Glen Etive.

Secondary Watersheds.—Once a river system has been broken up, following the development of subsequent streams along such lines of weakness as the Loch Linnhe and Loch Leven shatter-belts, secondary watersheds must originate as a matter of course in the isolated segments. According to the view adopted here, the low cols of the through-valleys of Scotland are, for the most part, such secondary watersheds in the process of development, rather than primary watersheds which have been all but obliterated by glacial erosion. That glacial erosion has, however, modified these cols is in some cases almost certain. Thus a powerful lateral stream which issues from the north directly upon the col of Glen Tarbert hangs distinctly above this col, while at the same time the main valley, where it crosses the col, is broad and open in its cross section. This combination of characters seems to necessitate a belief in powerful glacial erosion on the site of the col ; in fact, vigorous erosion is exactly what one might expect in such a situation, and W. B. Wright has emphasised its importance in relation to certain flat-bottomed, high-level passes trenching spurs of the Binnein Mòr massif north of Kinlochleven (Sum. Prog. 1908, p. 63 ; see also p. 275 of this memoir).

The through-valleys near their cols have, as a rule, very low gradients. This is admirably illustrated in Glen Coe and in the long upper reaches of the River Leven. The latter are now occupied by the Blackwater Reservoir supplying power to the Kinlochleven Aluminium Works (Pl. II, p. 8) ; and incidentally we may note that this reservoir has drowned the pre-existing watershed, and that it continues well to the east of it. It would, therefore, appear that the rivers of the original drainage system of our district had arrived at maturity before they were beheaded. Such a condition clearly favours the formation of long obsequent streams in valleys that had been broken up into isolated segments. A well-graded trunk valley, once it has lost a considerable proportion of its water through beheading, cannot possibly keep its course clear. One deltaic cone after another, built by tributary streams, obstructs the channel, and serves in succession as its corrom or delta-watershed. Supposing the tributary streams all of equal importance, the first stream down from the breach, by which the main valley has been beheaded, builds the first corrom. During its periods of self-imposed diversion, it receives increased erosive power, through access to the beheading river system, and thus is able to keep in check the further growth of its deltaic cone. The second stream meanwhile, sheltered, as it were, behind the first-formed corrom, carries on its work of deposit with increased vigour until eventually it establishes a second corrom to supersede the first. And so the position of the corrom is shifted farther and farther along, in what was originally the downstream direction of the main valley, until a position of equilibrium is reached—that is, until the remnant of the consequent drainage is truly balanced by the successive additions made to the obsequent stream.

The word corrom, which has been used above to signify a delta-watershed, is based on the Gaelic *cothrom*, a balance. The stream already mentioned, which issues upon the col of Glen Tarbert, is known as Allt a' Chothruim (the stream of the balance) since, at its point of entry, it has built up a great cone, upon which it is balanced, as it were, with the possibility of flowing either east or west. The name was borrowed from this Glen Tarbert example to describe delta-watersheds in general, once the physiographical importance of these structures was recognised by P. F. Kendall (Kendall and Bailey 1908, p. 8, foot-note).

The divide at the head of Glen Nevis is a corrom. As a matter of fact the present-day corroms of Glen Tarbert, Glen Nevis, and other valleys of this district have only a trifling importance in fixing the positions of the various watersheds which are fashioned essentially in rock ; but they may not unreasonably be taken as symbolical of pre-glacial corroms responsible for obsequent diversion with corresponding rock erosion.

In many through-valleys of the Highlands the modern watershed is not a corrom. In some cases this may have resulted from the shifting of the position of the watershed by glacial erosion, but it is not unlikely that in other instances landslips helped, in pre-glacial times, to determine the divides between the consequent and obsequent drainage of the segmented rivers. The watershed of the Lairigmòr valley is situated at the foot of Stob Bàn, the bulging flanks of which are constituted of landslip material (Pl. II, 2, p. 8). The slipped debris does not in this instance reach down to the valley floor, but it is easy to realise that a more extensive fall of rock in another instance might well turn the drainage of a beheaded river. A striking example of a landslip reaching right across a stream, and more or less blocking its course, is afforded in the valley of Allt Coire

Gabhail, on the south side of Glen Coe (Pl. VII, p. 139). A flat strath has been built up behind the landslip, but there has not been any chance of reversal of drainage in this case, since the valley here is steeply bounded and has not been beheaded.

Hanging Valleys.—Segmentation of a through-valley system, such as has been outlined above, may well rejuvenate a mature river system by a process of short-circuiting. This conception leads us to inquire into the origin of the hanging valleys of the district. First, it may be pointed out that the hanging-valley system shows evident trace of glacial action. A fine illustration of this is afforded by a hanging valley, or corrie, draining into Glen Nevis, 1½ miles east of Polldubh (Pl. I, frontispiece). A powerful stream issues from this corrie and races to the bottom of Glen Nevis, 1000 ft below. From the road we see the tributary stream standing out as a long ribbon of foaming water, for it flows down the untrenched slope of the main valley. The latter at this point is of **U**-shaped cross section, unhampered by projecting spurs ; it is the " canal " type of valley, as defined by Tarr. Aqueous and subaerial erosion could not have been so selective as to carve this gigantic hollow for the main river, without furnishing a gorge, however small, for the independent accommodation of the powerful tributary stream. A probable solution is that the present topography corresponds with a stage when a major glacier flowed down Glen Nevis, receiving an actively eroding tributary perched in the side corrie. Another somewhat similar example of a hanging valley is afforded farther up Glen Nevis by Allt Coire a' Mhàil, which is seen in the foreground of Pl. V before it cascades down an unnotched rock face at Steall (Pl. XIII, 1, p. 275).

Turning to a side issue we may mention that this Steall waterfall affords an interesting illustration of how erosion is sometimes actually hindered by steepness of grade. At the foot of the fall one can pick up rounded pebbles smashed in two. They have been brought to the edge of the fall and hurled down without an opportunity of doing effective work. Above the waterfall the gradient is much less pronounced, and the pebbles, retained in pot-holes, have succeeded in lowering the bed of the stream, some 30 ft in places, since the glaciers retired.[1] The fall, it is true, is over quartzite, and the pot-holes above are cut in hard mica-schist, so that the comparison which has just been made must not be emphasised too strongly.

The important point, to return to the question of glacial erosion, is that the Steall waterfall, where it passes over the quartzite, has no bounding walls, although the rock on either side is a continuation of the same quartzite as is washed by the descending waters. It seems incredible that this condition could have been fully developed without glacial intervention.

But inquiry cannot cease here with the mere recognition of ice-work in the development of the present-day hanging-valley system. Scottish geologists are well-nigh unanimous in regarding glacial erosion as responsible for the majority of the rock basins of the Highlands.[2] It is unnecessary, therefore, to point out that on this assumption many tributary valleys in one part or another of the country must have been left hanging through glacial over-deepening of corresponding trunk valleys. It is well, however, to consider each case on its merits, and, accordingly, it is advisable to inquire whether glacial *over-deepening* can be called in to explain the hanging tributaries of Glen Nevis. This glen affords an imposing example of a **U**-shaped canal valley in the four miles of its course in which it drains north-westwards towards the open country near Fort William. Several minor hanging tributaries rush swiftly down its slopes from Ben Nevis. At Polldubh the glen turns so as to run east and west, and at the same time it is narrowed by a projecting spur of very hard contact-altered mica-schist. The valley thus constricted exhibits the **V**-shaped cross section of well-advanced river and subaerial erosion ; it is therefore very difficult to believe that ice can have had any effective part in the erosion of the glen at this point. This inference is much strengthened by the **V**-shaped cross section of two powerful tributary valleys, Allt a' Choire Dheirg and Allt Coire a' Mhusgain, which enter Glen Nevis at Polldubh in normal adjustment with the level of the main river. Thus it appears that at Polldubh a pre-glacial section of Glen Nevis is preserved, and, as this does not hang above the canal portion of the valley farther downstream, it is a fair inference that the latter has not been over-deepened by glacial erosion, however much it may have been widened. Above Polldubh, Glen Nevis is again for a couple of miles of the " canal " type, and receives from the north the waters of the particularly fine hanging valley to which special attention has been drawn already. Then beyond a right-angled bend as we ascend the glen, the river for half a mile flows hurriedly through a deep and narrow gorge cut in the base of a high-level gap which shows intense glacial erosion. This gorge is a very minor feature of the glen taken as a whole. Its position is marked in Pl. I by the downstream disappearance of the Water of Nevis. It cannot be of post-glacial origin, for it shows ice-moulding almost to the very bottom. It is at the same time far too narrow to be the direct work of glacial erosion. Thus here, as at Polldubh, it would seem that a pre-glacial section of Glen Nevis has escaped with little modification.

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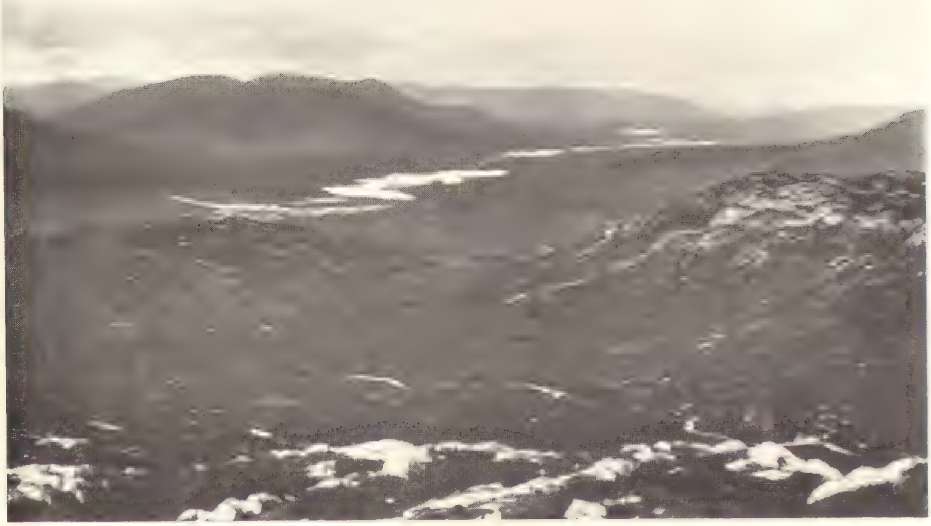
[1] It must not be supposed that the gorge seen in the photograph above the fall is post-glacial. On the contrary, it is glaciated almost to the bottom, where pot-holes appear.

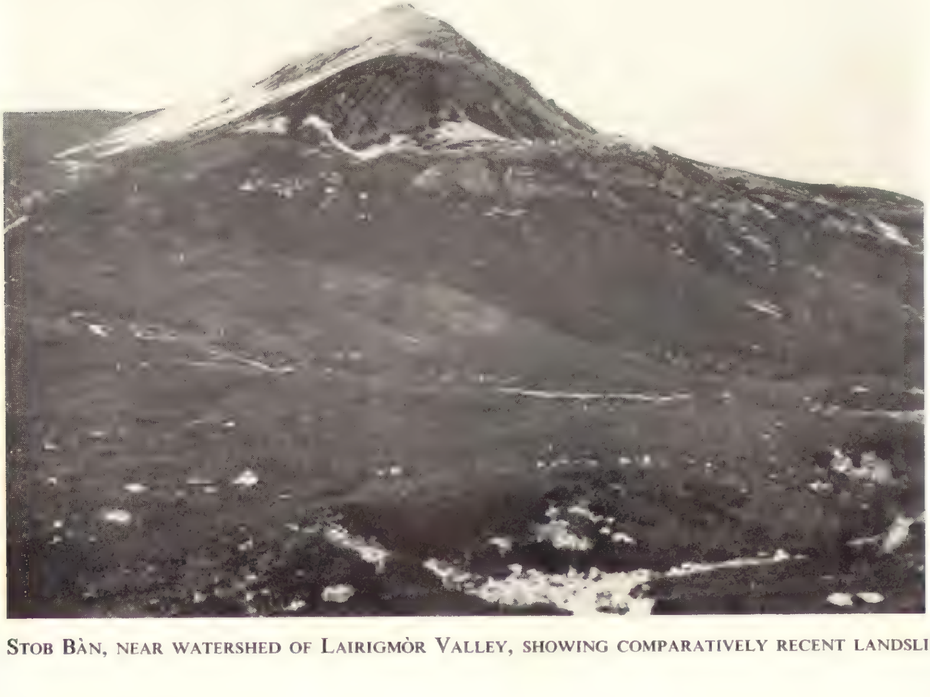
[2] No more convincing example can be given than Loch Coruisk, described by A. Harker (1901a, p. 238). Many other authors might be cited, and the subject has been most completely dealt with by Peach and Horne in their report of 1910.

Altogether Glen Nevis affords fairly satisfactory evidence of the existence in this district of a hanging-valley system, which has not been determined by glacial over-deepening. This inference is corroborated by an inquiry into the drainage system of the River Leven. The upper reaches of the Leven valley are thoroughly mature, and belong to a widespread high-level valley topography, which includes in the clearest possible manner the hanging portions of the downstream tributaries of the Leven itself. A little below the Blackwater Reservoir, which now occupies the site of the string of lochans marking the river course in Pl. II, 1, the river plunges from its high-level to its low-level valley in a series of waterfalls. The form of the entire low-level valley from the falls to the sea does not suggest glacial but aqueous and subaerial erosion. Allt a' Choire Odhair-bhig and Allt a' Choire Odhair-mhòir, tributary streams which join the Leven less than a mile below the falls, have done very little to adjust themselves to the low-level valley ; Allt na h-Eilde and Allt Coire Mhorair, which enter more than a mile farther downstream, have, however, eaten their way back, so that their hanging portions are well removed from the valley edge.

The case of Allt na h-Eilde draining Loch-Eilde Mòr is particularly important. The lip of the hanging valley in this instance is cut back for a mile from the Leven. The stream tumbles over the lip in the form of a waterfall and reaches a low-level valley. The latter is graded with the Leven, and yet, so far as one can speak with confidence in such matters, it is obviously not the work of glacial erosion—although, at the same time, it has suffered a certain amount of glacial mod-



1. HANGING PORTION OF RIVER LEVEN WITH DAM SITE OF BLACKWATER RESERVOIR



2. STOB BÀN, NEAR WATERSHED OF LAIRIGMÒR VALLEY, SHOWING COMPARATIVELY RECENT LANDSLIP

ification. Since then we may take it that this lower adjusted portion of the Allt na h-Eilde is pre-glacial, it follows that the deepening of the Leven valley is pre-glacial too—an inference which many would regard as justified on a consideration of the form of this valley taken by itself.

Industrial development has emphasised this beautiful example of hanging scenery. Since the photograph of Pl. II was taken, conduits have been built approximately along the 1000-ft contour on both sides of the River Leven—on the north side leading from Loch-Eilde Mòr to the Blackwater Reservoir and on the south from the reservoir to intake pipes that descend in switch-back fashion to Kinlochleven. Once one reaches the southern conduit one is provided with a concrete path on old scenery belonging to what Peach and Horne have called the " intermediate plateau of the Highlands," while immediately below lies new scenery incised with reference to present-day sea-level at Kinlochleven.

Peach and Horne's " intermediate plateau of the Highlands ", figured with its lochans in Pl. II, 1, reappears to the south as the Moor of Rannoch (R. in Fig. 1), where it is the eastward continuation of the through-valley of the Coe. The contrast between the Moor of Rannoch and Glen Coe is particularly striking. The Moor is cut in Moor of Rannoch " granite " which has proved itself to be easily erodable. The Glen is cut in more resistant volcanic rocks. The Moor and Upper Glen Coe have approximately the same bottom level, so that it seems certain that Glen Coe must have been opened up to some extent by the processes of erosion which, in pre-glacial times, fashioned the Moor. Also much of the pre-glacial opening up must have continued long after the westward reversal of the Coe, since this reversal was followed by the opening up of a long stretch of Lower Glen Coe and its concordant tributary, Fionn Ghleann. Upper Glen Coe hangs to Lower Glen Coe where rhyolite lava crosses the glen two miles upstream from Loch Achtriochtan. Further details are included in accounts of two Glen Coe excursions, pp. 72, 137.

If we take the Leven and Coe together we reach the conclusion that the original drainage system of the district, having reached a stage of maturity, became in part rejuvenated as a result of widespread beheading and resultant short-circuiting : the main valleys were cut back by waterfall and cataract action ; the tributary valleys made use of their opportunities as soon as presented ; a hanging-valley system was thus developed, such as occurs in the Zambezi district at the present time (*cf.* Lamplugh 1907) ; then followed intense glaciation ; in many cases trunk valleys were opened out, side spurs were truncated, and the walls of certain minor hanging tributaries totally obliterated.

It appears, then, that the glaciation of this district has accentuated a hanging-valley system previously in existence. Concurrently it has often produced very obvious results in the modelling of the walls and bottoms of the various glens in addition to the removal of lateral spurs. Allt Coire an Eòin, flowing north-east from Aonach Beag of the Ben Nevis group, and Amhainn Coir' an Iubhair, entering Glen Tarbert near Loch Linnhe, occupy valleys which are particularly well worthy of a visit in this connection. Their *moutonné* surfaces convey to even a casual observer a more vivid impression of the immense grinding power of ice than would reams of description. In such cases grinding has sometimes been associated to a quite obvious extent with plucking, the importance of which has been emphasised by American geologists. Pl. XIII, 2 (p. 275), shows a *roche moutonnée* by the roadside in Glen Nevis partially destroyed by plucking, which has removed a great block thus interrupting the beautiful curving outline imparted to the surface by previous grinding. Morainic drift is banked some little way up against the broken surface.

Corries and Landslips.—At the head of Allt Coire an Eòin and Amhainn Coir' an Iubhair, one enters upon truly magnificent corries, as fine as any in Scotland. Corries, indeed, are a characteristic feature of the physiography of this district in general, and accordingly we shall now pass on to consider how such great cliff-bound amphitheatres can have originated.

There is a general consensus of opinion that corries are restricted in their typical development to glaciated lands, and are therefore of glacial origin. From the preceding discussion of through-valleys and hanging valleys, for which, as we have seen, a similar claim is also advanced, it will be evident that this line of argument must be followed with great caution ; still it seems to the writer that the case for the glacial origin of corries has been established. The only agency at present at work in the district which might be regarded as responsible for the production of corries is landslipping. Reference has already been made to big landslips on Stob Bàn above the watershed of the Lairigmòr valley (Pl. II, 2, p. 8). There are many other important landslips, especially in the Coire na Bà glen, in the valley east of Binnein Mòr, in the Allt Coire Rath glen, and on the two sides of the long ridge which separates Allt Coire Rath from Allt Coire an Eòin. Behind the slipped material a hollow is left, which is often of semi-circular form and backed by steep crags. C. T. Clough, in his description of the Cowal district of Argyllshire (1897, p.276), has pointed out that hollows thus left by landslips often resemble corries ; in fact, some of the larger landslip-hollows are actually small corries. He has further suggested that many of the crag features of Highland valleys may be due to pre-glacial landslipping followed by glacial removal of the fallen material. Such may well be the case.

Where slipping occurs along the two sides of a straight ridge, the cracks limiting the slips are sometimes straight themselves, and determine the production of a more or less continuous " knife-edge " *arête*. The best locality to convince any observer of this peculiarity, and of the considerable importance of landslips generally in shaping the physiography of some parts of this district, is the ridge summit separating Allt Coire Rath from Allt Coire an Eòin. Here one may examine not only innumerable slips but also vertical cracks which extend deep down into the solid rock in preparation for the fall of other great masses. In almost every instance the knife-edge character of the ridge has been maintained, but a little south of Stob Coire Easain the divide has been breached ; in this case a high-level col has been formed, and the slipped material, which has travelled to the west, has built a prominent little hill (" Meall Tionail "), easily recognised even from a distance of several miles.

Many of the landslips referred to above have probably resulted from the instability of valley sides over-steepened by glacial erosion. Slipping in such cases is a step towards the re-establishment of gentler gradients, although its immediate result is often to produce cliffs and crags. Special conditions, tending to repeated landslipping, and the rapid transport of slipped material, are required for really successful corrie formation. Such conditions are apparently afforded at the *bergschrund* of a glacier—the crevasse, that is, which forms every summer between a glacier-head and the containing valley. The bergschrund is in many respects analogous to the landslip cracks which occur so abundantly in some parts of the present district. The tug of the glacier before the bergschrund forms will be a powerful incentive to landslipping on a large and small scale, while the glacier itself is admittedly an efficient carrier of slipped material.

The importance of the bergschrund in connection with corrie formation was first suggested by Johnson (1904). In 1883 he descended a bergschrund at the back of a miniature glacier of the Sierra Nevada. The crevasse was about 150 ft deep and for the most part was walled on both sides by ice. About 20 or 30 ft from the bottom, the fissure reached the valley side, and from this point down the parting had taken place, not between ice and ice, but between ice and rock. Johnson found that the zone of bare rock thus exposed bore evidence of intense and repeated frost action. In fact, he regards this localised frost action as the main element in the problem of corrie formation, although he states that plucking likely supplements the initial rupturing due to the frost. We are, however, inclined to lay greater stress on the plucking, but this is a point which can only be settled by further investigation of present-day glaciers. According to another view elaborated by Harker (1899, p.487), the bergschrund is not taken into consideration, and corrie formation is attributed to direct glacial grinding. '' Erosion,'' he points out, '' near the sources of a river is very feeble ; a glacier, on the other hand, springs into being, like Athene, fully armed.'' Maufe noticed that, while the bottom slope of the great Ben Nevis cliff overlooking the head of Allt a'Mhuilinn is strikingly smoothed and striated, the cliff itself is rough as though it owed its form to plucking.

The corries of the district seem to favour a north-easterly aspect. One realises this on looking north from Bidean nam Bian across country towards Ben Nevis. The coincidence is not sufficiently striking, however, to need special explanation were it not that many observers in various northern lands have noticed a similar orientation. The effects have been very reasonably ascribed to the conjoint influence of sun and wind upon the course of glaciation, for even now the snow lies long in shady hollows whither it has been drifted before the prevailing westerly gales ; thus, in the great corrie of Ben Nevis, there are patches of snow which are scarcely ever entirely dissipated by the summer's heat.

Rock-Basins.—We may now pass on to notice a few instances of glacial overdeepening recorded in rock basins within the limits of the present district, some of which are included in the Murray-Pullar survey (1910). Loch-Eilde Mòr and Loch-Eilde Beag are probably, both of them, rock basins. They are situated on the shatter-belt which has determined the position of Loch Leven. Loch-Eilde Mòr is 100 ft deep. The shallow lochans in the flat upper reaches of the River Leven almost certainly include rock basins. Loch Achtriochtan in Glen Coe is another example. Maufe has pointed out that this loch lies in soft phyllites behind a barrier of relatively harder rocks which here cross the glen on the down-stream side of a powerful fault ; differential erosion of the softer material has given rise to the loch basin. Loch Coire na Creiche among the mountains on the other side of Loch Linnhe may also be cited as a clear example of a rock basin. Other rock basins might be mentioned, but the only ones of any size are those which probably exist submerged beneath the salt waters of Loch Linnhe and Loch Leven. Closed basins undoubtedly occur along the beds of these two lochs, as is clearly indicated by soundings ; and, while some are due to accumulations of gravel, as at the narrows of Corran, North Ballachulish, and Caolasnacon, others, it is reasonably certain from analogy, are attributable to rock barriers (*cf.* J. Geikie 1894, chap. xix).

Various.—Enough has now been said of glacial erosion. Glacial accumulation also deserves attention as a formative element in the topography. The main glacial accumulations are of the nature of morainic debris, more or less restricted to the valleys. Well-shaped moraine ridges are rare, but a few occur, including a fine terminal crescent on the lip of the Allt Coire Giubhsachan valley, where the latter overhangs Glen Nevis. Most of the morainic drift has a hummocky surface. There is no more characteristic type of scenery than that afforded by hummocky drift where developed to perfection, as in the upper reaches of the River Leven valley and on the Moor of Rannoch at the head of Glen Coe.

A few words may now be added in regard to certain post-glacial and late glacial changes in the physiography of the district.

The summits of the high ridges were certainly exposed to frost action during late glacial times when the valley bottoms were still occupied by glaciers. This has contributed to render the results of frost conspicuous on many of the mountain tops. It is common, where the slope is gentle, to find the whole surface littered with slabs and fragments which have been prized loose by water freezing in joint fissures, but which have not travelled appreciably from their original source. The great domed surface of Ben Nevis affords a capital example of such an accumulation merging insensibly into genuine scree on the steeper slopes. On other mountain tops the debris covering, especially where it is composed of comparatively small fragments, has crept forward in a succession of steep-fronted, flat-topped waves or terraces. The movement appears to take place in times of storm, when rain is driving, and the whole surface is laden with water. In exposed situations the direction of movement, as indicated by the steep fronts of the terraces, is clearly determined rather by the direction of the prevalent gales than by that of the hill slope, so long as the inclination of the latter is not pronounced. In such cases any heather that manages to survive has assumed a prostrate habit and turned its head away from the blast. Patches of the surface are swept bare, and Lilliputian lochs are excavated with miniature storm-beaches to match. The turf in front of the advancing terraces of debris is turned up on end, broken and overwhelmed.

Frosts and torrents have been busy, too, among the cliffs and crags, picking out every little shatter-belt, and thus dissecting the relatively smooth surface left by glaciation. Great gullies have been cleared, and debris sent hurtling down to build widespreading cones of scree on the lower slopes. This type of frost action is illustrated very finely in Glen Coe, where precautions have been taken to prevent the scree from encroaching upon the road in times of flood. One can see that this scree formation, like the large-scale slipping so pronounced in the district north of the Leven valley, is busily undoing the work of the glaciers, and tending to produce a topography more in harmony with existing conditions.

While the ridges show signs of the severe treatment to which they have been exposed since they emerged from the glaciers, the stream-courses have also suffered to some slight extent. Many of the rivers have cut gorges a few feet deep, and it is interesting to see how their mode of attack varies with the nature of the rock. If, for instance, the stream is crossing quartzite, it quarries out fragment by fragment, making use of joint and bedding planes ; if, on the other hand, mica-schist has to be removed, pot-holes are drilled, or a continuous channel is ground out with smooth flowing contours. Beautiful examples of breached pot-holes, forming arches through which the water plunges, may be seen from the road where Allt Nathrach runs down to join Loch Leven.

But of all post-glacial changes, the most important from the human point of view is one that is limited to the coast-line. A more or less continuous terrace, often backed by low, rocky cliffs, fringes the shores of Loch Linnhe and Loch Leven, and carries most of the roads of the district and the railway leading to Ballachulish. It is a record of the activities of the sea at a time when the land stood some 30 ft lower than at present. Fertile beach deposits, dating from this period, have determined the sites of the crofting villages of Onich, North Ballachulish and Clovulin.

We may bring this discussion of the physiography of the district to a close by considering the influence of rock structure, which is responsible for many conspicuous minor features. Most of the country is composed of crystalline schists of various kinds, each with a more or less characteristic type of weathering. Thus white quartzite, interfolded among darker mica-schist, is strongly developed in the district between Ben Nevis and Glen Coe, and gives rise to remarkable scenic effects (Pls. II, 2 ; V ; XIII, 1). In Glen Coe itself, lavas of Old Red Sandstone age occur in striking contrast to the surrounding schists. Here the abrupt face of Aonach Dubh, built up of tiers of andesite flows, capped by rhyolite and agglomerate, at once attracts attention. The ridges that follow to the east, the two first of which, together with Aonach Dubh, constitute the Three Sisters of Glen Coe, are largely composed of rhyolite, with a peculiarly grand and massive type of scenery (Pl. VI), reaching its culmination in Stob Dearg (Pl. VIII). There are also several plutonic intrusions in the district with a typical amorphous outline well illustrated in the hills formed of the Ballachulish quartz-diorite in Creag Ghorm and the Glen Scaddle " epidiorite " across Loch Linnhe. In the southern portion of the map a small part of the Etive " granitic " complex is included. This complex is divided into an outer rim and an inner core. Mountains constituted of the granite of the inner core, the Ben Starav Granite, are altogether remarkable for the extreme bareness of their slopes, which recalls the nakedness of the Norwegian Highlands.

Contributions to Interpretation since the First Edition.—The foregoing account of river development within Sheet 53 (Geol.) was composed under inspiration gained from the writings of Cadell, Mackinder, Peach and Horne, dealing mainly with other parts of Scotland. Since then a fairly extensive related literature has appeared, again chiefly concerned with outside districts. Some of the conclusions reached are in harmony with those set out above, while others are discordant. Among the former we find that both Bremner (1942, p. 54) and Linton (1951b, p.68) consider that east, rather than south-east (the latter favoured by Mackinder, Peach and Horne), is the characteristic direction of consequent streams in the Highlands. East is the direction indicated in Fig. 1.

Bremner's other general conclusions, right or wrong, introduce no special difficulty. For instance he thinks that the consequent streams suggested in Fig. 1 started on a tilted uplift carpeted with Upper Cretaceous sediments. He imagines that the site of the Hebridean volcanoes was " most strongly upheaved ", so that consequent rivers radiated from it to begin, as he puts it, " the cycle of erosion that produced the Tertiary peneplain—the High Plateau". According to this conception, the volcanoes, situated on a high western land of hypothesis, did not, on their arrival, materially affect the eastward drainage across our district.

He regards the basin of the Irish Sea as due to depression in early post-uplift times. He does not, however, specifically refer to the Hebridean subsidences responsible for taking Tertiary lavas and underlying Cretaceous sediment in many places below present-day sea level ; but he does remark that " the volcanics themselves fell a prey to the subaerial forces of denudation and now enter into the substance of the peneplain ". Presumably this refers more especially to the Cuillin summits of Skye, composed of Tertiary gabbro and yet planed off at approximately 3000 ft.

Hans Cloos (1939) has given a closely similar picture. He thinks he can recognise a dome-shaped bulge, of which Great Britain constitutes the eastern portion and Ireland and the Outer Hebrides the western. In between he regards the Irish Sea and the Hebridean subsidences as a rift-valley, due to collapse of what had been for a time the most elevated belt of the upward bulge.

Linton (1951b) differs from Bremner and Cloos, for he speaks as though the Hebridean subsidences (or relative subsidences) dated from the beginning of the post-Cretaceous upheaval. " If our eastward slope," he says, " broke towards the west along the margins of the ' Hebridean Rift ' there must from the outset have been two sets of rivers, the one set flowing eastward to the North Sea depression, the other westward into the Rift ".

He thus pictures " from the outset " a watershed or watersheds on the Scottish mainland dividing eastward- from westward-draining rivers. Many of these oppositely directed rivers today occur in pairs, each of which occupies a through-valley ; but he cannot accept the suggestion that many a pair originated as a single eastward-flowing stream. " If this is so," he asks, quoting J. Sölch, " where are the western mountains from which those rivers came ? " The answer of course is another question : Where are the thousands of feet of hard solid rock that presumably once covered the gabbro summits of the Cuillins ? All of us are merely groping our way towards a clearer understanding.

Linton, like Tarr, whose work is mentioned earlier in this chapter, is a firm believer in most of the through-valleys of the Highlands having originated as a result of glacial erosion. He has examined some with care, and has satisfied himself that he can reconstruct the approximate position and form of watersheds that have been almost obliterated by what A. Penck has termed glacial transfluence. He has rendered good service by directing attention to overseas publications on this subject. It is, however, surprising to read that " transfluence was first recognised in Scotland, though not called by that name, by Peach and Horne thirty years ago " (Linton 1951a, p. 11 ; the reference given is Peach and Horne 1910). Surely the phenomenon has been familiar to all Scottish geologists since Jamieson wrote of ice passing from upper Glen Roy into the Spey valley and from Loch Fyne into Crinan Loch (1862, pp. 176-7). Geologists, who have adopted a through-river interpretation of some of the through-valleys of the Highlands, have from the first been conscious that most of these through-valleys have been occupied at some stage of their history by through-glaciers eroding as they went. There is obvious room for difference of opinion in this matter. Tarr, Linton and others have dispensed with through-rivers and emphasised through-glaciers. Readers are recommended to study the glacial interpretation of through-valleys in the original publications. Linton in (1951b) and Dury in (1953) give long and useful lists of references.

Those who visit Sheet 53 (Geol.) will probably pass through Glen Coe. They should pause at Lochan na Fola to form their own judgment as to whether or no existing topography suggests that here an important watershed has been breached by glaciation. Also, even if they cannot visit them, they should note on the map the curious position of the watersheds of Glen Nevis, near Tom an Eite, and of Glen Tarbert, at Lochan a' Chothruim. In both cases the watershed corresponds with the advent of important tributary streams. This hardly looks like the location of a main pre-glacial watershed, unless the latter was built pre-glacially as a corrom across a beheaded through-valley—both sites, it will be remembered, are occupied by post-glacial corroms. Then too the pre-glacial hanging topography of Upper Glen Coe and the Moor of Rannoch, and of the Blackwater Reservoir should be taken into careful consideration. E. B. B.

CHAPTER II

HISTORICAL REVIEW

HIGHLAND SCHISTS

Early Work.—In 1810 T. Macknight (1811, pp. 307-357) traversed a considerable portion of the Western and Central Highlands of Scotland, and visited many points of interest in the district dealt with in this memoir. He viewed all geological phenomena from the standpoint of Wernerian doctrine, and found no evidence in favour of Hutton's theories regarding the metamorphism of the schists or the igneous origin of granite. Thus he thought that the schistose strata had been precipitated from a primitive ocean, and that their quartz veins, high dips, crinkling, and contortion were all developed during the process of accumulation. He expresses keen satisfaction in having been able to trace a succession from the clay-slate of Ballachulish, through the mica-slate of the Fort William shore of Loch Linnhe and the gneisses of Ardgour, to the " granite "[1] of the western end of Glen Tarbert. This he evidently regarded as a normal downward sequence of deposit ; in Glen Coe, however, and Ben Nevis, he found a development of " granite," and other rocks classed in this memoir as igneous, which he assigned to an overlying formation of later date than the surrounding schists. Macknight also recorded the association of limestone with the slates at Ballachulish, and the occurrence of both granular quartz and limestone at Onich.

J. Macculloch's writings at once strike a different note (1814). He showed that the quartzites of Jura, Ballachulish, and Assynt are, in large measure at any rate, true mechanical deposits, since they contain worn and blunted pebbles of quartz and felspar. He further drew attention to various sections in which the Jura and Ballachulish quartzites are overlain by, or interbedded with, clay-slates and mica-slates ; and on the basis of this association he argued that the slates, like the quartzite (granular quartz), had originated as detritus, and not as crystalline precipitates from Werner's primitive ocean.

Incidentally, in the presentation of his evidence, Macculloch has given an excellent account of the transition zone linking the quartzite of Ballachulish, that is the Appin Quartzite, with the well-known Ballachulish black slates (1814, p. 483). We quote the following :

> 33. Fine sandstones, not to be distinguished from the floetz sandstones, and, like many of them, striped in endless alternations by black clay. From the series at Ballachulish. These belong to the quartz rock, which alternates with clay slate, and show the transitions between these two substances.

The term " floetz sandstones " used in this description merely signifies normal sandstones of such formations as the Carboniferous System.

Later, Macculloch (1817, p. 126) drew attention to the fact that the Ballachulish " granite " metamorphoses the schists in its vicinity, and sends veins into them, and, further, that it contains innumerable fragments of these schists as inclusions. But Wernerian theories still dominated Macknight (1821) who, returning to the district, described the contact-altered rocks round the Ballachulish " granite " as gneisses occupying their normal position in his imaginary granite, gneiss, mica-slate, clay-slate succession. Macknight now regarded the

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[1] The term " granite " between inverted commas covers in this memoir both granite and quartz-diorite.

Ben Nevis " granite " as probably part of a great underlying mass, forming the foundation of the Scottish Highlands ; the rocks of the upper portion of the mountain (the lavas) he correlated as before with the Glen Coe complex, and interpreted them as an overlying formation.

Both Macculloch (1819, p. 265) and Macknight refer to the limestone of Lismore, which extends into the southern edge of the present map, and is continued northwards into Shuna. Macculloch rightly points out the resemblance of this limestone to that of Islay. In 1836, a year after his death, Macculloch's geological map of Scotland was published (*cf.* Eyles 1937 ; 1939). In this he indicated in a generalised manner the positions of many of the limestone, quartzite, and clay-slate outcrops of the district, especially in the neighbourhood of Loch Leven and Portnacroish (Appin railway station).

The igneous origin of the Ben Nevis complex had been confidently denied by Macknight. C. von Oeynhausen and H. von Dechen (1830 ; 1834), however, pointed out that the " granite " has forced its way through the surrounding gneiss and schists, and that it extends laterally into these rocks in the form of veins. It is interesting to find them referring in their descriptions of Glen Nevis to " a rock composed of alternate laminae of white felspar and green mica " which occurs, for a considerable distance, bordering the granite margin. This curious rock has since been shown by J. S. Grant Wilson and J. J. H. Teall to be a calc-silicate-hornfels produced by thermal metamorphism from a thick mass of schistose limestone (Sum. Prog. 1898, p. 66) ; but for many years its nature was not understood, and in the earlier maps of the district it is always classed as " gneiss ". Von Oeynhausen and von Dechen also drew attention to the grey, granular limestone of the Spean section, which is situated not far north of the limit of the district at present under discussion.

Nicol (1844, p. 165) recognised, probably from the summit of Ben Nevis, that quartzite plays an important rôle in the geology of the country lying between Glen Nevis and Glen Coe. He expressed the opinion that the quartzite here forms the tops of many of the hills, and we find this theory of an overlying quartzite constantly recurring in his later writings. Thus he groups together the quartzites of Islay, Jura, and Loch Linnhe, and maintains that they " cannot be older than the Lower Silurian Period " (1858, p. 5) and that they are associated with mica-slate upon which they appear to rest. On reading paragraphs *f* and *g* of Nicol's note, there can be no doubt that he correlated the quartzites mentioned above with those of the North-West Highlands.

Murchison (1859, p. 420) adopted similar views in that he provisionally classed the quartzites and limestones of the Loch Linnhe district with the fossiliferous deposits (now known to be Cambrian and Ordovician) of north-west Sutherlandshire. Later he elaborated this interpretation in conjunction with Archibald Geikie (1861, pp. 171-240). Finding opposing dips on the two sides of Loch Linnhe near Fort William, they postulated an anticline along the line of the loch, bringing up the Sutherlandshire series from beneath the general gneiss and schists of the Highlands. It is strange to find that Nicol's hypothesis of an overlying quartzite is here turned upside down without involving any change in his correlations. It is now acknowledged, however, that it was quite impossible, either for Nicol or for his successors, to arrive at any true conception of the structure of this district as a result of brief visits. This latter-day caution is, in fact, foreshadowed in Murchison and Geikie's own paper, for in it they insist on the presence of isoclinal folds as an important factor in the structure of the Highlands (1861, pp. 201, 203, figs. 17, 18). It must be added that the correlation put forward both by Nicol and Murchison of the Loch Linnhe quartzites with those of Sutherlandshire carries very little weight at the present day. In this matter also the need for caution has been increasingly recognised.

Harkness followed with a paper inspired by Murchison's generalization regarding the age and position of the Highland schists. He draws a section across the Ardsheal peninsula, north of Cuil Bay, showing schist (Cuil Bay Slates and Appin Phyllites) lying in a syncline above quartz-rock (Appin Quartzite) with locally a band of limestone (Appin Limestone) intervening (1861, fig. 8, p. 266). It is probably no more than a coincidence that this interpretation agrees with the views at present in vogue, for it is doubtful whether Harkness found sufficient local evidence to indicate the synclinal structure of this peninsula.

In a final paper on the district, Nicol regarded the clay-slate, limestone and quartzite of Appin and Ballachulish as unconformable to the mica-slate, and as probably belonging to an overlying formation. In bad weather he visited sections in Glen Nevis, and these again led him to suspect the presence of an unconformable overlying quartzite (1863, pp. 205-206). Apart from this question, Nicol gives an interesting account of the schistose beds—partly " clay-slate," partly " mica-slate "—which intervene between Loch Leven and the southern edge of the map (1863, p. 202). He draws special attention to the frequent cross-foliation of these rocks, and, led astray by definite segregation of quartzose material along cleavage planes in the more micaceous layers, he concludes that the foliation must have originated under the same conditions as the bedding.

Cuil Bay Slates to Glen Coe Quartzite.—The Geological Survey entered the district in 1895, and published a succession of brief notes in Annual Reports for 1895-6 and in Summaries of Progress for 1897-1908 and 1912 (see List of References). At first the field work on the schists was wholly in the hands of J. S. Grant Wilson, with petrological support from J. J. H. Teall. Wilson's task was to block out the main features of the geology in a minimum of time. In 1902, when Teall became Director, B. N. Peach's responsibility as District Geologist was strengthened ; and next year he had three Geologists placed under his leadership, with H. B. Maufe (Muff) and E. B. Bailey joining Wilson. More detail was expected, and less stress was laid on rapid accomplishment. In fact eventually much of what may be called the preliminary survey was given a quick revision in the light of later discoveries. In 1904 C. T. Clough took over from Peach, and G. W. Grabham was added to the group, followed in 1906 by W. B. Wright.

We shall defer discussion of Ardgour till chapter ix, and of the Lismore Limestone outcropping in the island of Shuna till p. 42. Also, to begin with, we shall confine our attention to schist groups lying between the Cuil Bay Slates and the Glen Coe Quartzite inclusive. The succession in this sequence is now known to be :

Cuil Bay Slates, black—*youngest*
Appin Phyllites, grey
Appin Limestones, white
Appin Quartzite, gritty
Ballachulish Slates, black
Ballachulish Limestone, dark limestone against the Ballachulish Slates, calcareous schist in the middle, thin cream-coloured limestone against the Leven Schists
Leven Schists, grey
Glen Coe Quartzite, fine—*oldest*

The names used above are all chosen from Sheet 53 (Geol.) and in what follows will be substituted for alternative names employed in early descriptions, some of which were based on faulty correlations.

In 1895 Grant Wilson was able to show the Director General, A. Geikie, several interesting geological features between Fort William and Onich. We read in the latter's account (Ann. Rep. 1896, p. 25) that a " grey normal " limestone (Ballachulish) is associated with black schist (Ballachulish) which is folded with quartzite (Appin) north of Gleann Seileach ; and that " between this glen and the shore [at Onich] a white limestone [Appin], folded with the quartzite, but without any associated black schist, may be a distinct band," different, that is, from the grey band noted above. This account gives us a preview, as it were, of the succession now accepted from Appin Phyllite to Ballachulish Limestone.

In 1898 Wilson in the same area seems to have realised, though with some confusion, the synformal disposition of Ballachulish Slate over Ballachulish Limestone (Sum. Prog. 1899, p.46), well displayed in the south wall of Glen Nevis overlooking Glen Nevis House (Fig. 3, p. 39) ; and later he drew attention to spectacular recumbent folding on a moderate scale affecting Glen Coe Quartzite at Stob Bàn, four miles to the south-east (Sum. Prog. 1902, p. 123).

Peach after one season's work with his staff of three offered a tentative appraisal of the schist succession in the Ballachulish district (1904, p. 66). This recognised that the Appin and Glen Coe Quartzites are distinct, an important point contributed by Wilson. Otherwise the statement was sorely muddled by miscorrelation of Appin Limestone with the cream-coloured edge of the Ballachulish Limestone, and of Appin Phyllites with Leven Schists. Peach had not found time to visit previously-mapped ground, including that lying north-east of Onich. Moreover, both he and Wilson started with the preconception that the Appin Quartzite was unconformable and might be folded in among outcrops of associated formations almost promiscuously.

If, however, we exclude all thought of the Appin Phyllite and Limestone, Peach's summary of 1904 does give an easily recognisable account of the lithology of the normal stratigraphical succession connecting the Appin and Glen Coe Quartzites (Pl. III, p. 55). In addition Maufe reported in some detail on a very special succession with Glen Coe Quartzite at its base, which outcrops along Glen Coe from Bridge of Coe to Clachaig Hotel (1904, p. 67). This succession owes its peculiar character to the Ballachulish Slide, as yet unsuspected (Fig. 10, p. 70).

The exceptional Glen Coe succession passes south under a great cover of Leven Schist in Meall Mòr and Allt na Muidhe, to reappear four miles away, with minor modifications, in what have since been called the Windows of Etive. Here Clough began mapping it (1905, p. 65), though unaware of its underground connection with Glen Coe. Here too, Maufe, in completing Clough's survey, came to a wonderful realisation of great recumbent movements (1906, p. 91). He found that the Glen Coe Quartzite exposed at the base of the Glen Coe succession in the bottom of the local glens is repeated above the thick Leven Schist cover so as to cap the neighbouring mountains. This discovery will be farther discussed on p. 87.

Next year, 1906, two important revisions were undertaken, the results of which were practically unrecorded at the time, though they greatly influenced later developments. In one day the writer remapped the Ballachulish district between the River Laroch and Beinn Bhàn, and in doing so established the stratigraphical succession of Appin Phyllite, Appin Limestone, Appin Quartzite, Ballachulish Slate, that had been suggested ten years before in the Onich region. Another result was the vindication of Macculloch's transition zone between the two last-named formations ; and still another, the tracing of three fold-faults ; but the site of the Ballachulish Slide was not visited on this occasion.

Later in 1906, Clough and Wilson carefully revised the continuation of the same belt of complications southwards past Loch Baile Mhic Chailein to the edge of the map. They were unable to resolve some of the statigraphical puzzles, but they refined the mapping of outcrops and recognised certain fold-faults, among them one that has since been called the Sgòrr a'Choise Slide. The evidence investigated in 1906 by the writer and by Clough and Wilson does not, in isolation, suggest large-scale tectonics ; but it is of prime importance when considered in relation to what is found in neighbouring districts.

In 1908, when the mapping of both schists and igneous rocks in Sheet 53 (Geol.) was all but completed, the writer spent a fortnight visiting key exposures. The Callert district (Fig. 8, p. 50) was taken first, and, along with a geological manuscript copy of Sheet 53 as a whole, it gave a complete picture of the Ballachulish Recumbent Fold and Slide, both of them refolded. This was supplemented, in company with Maufe, by a comparison of the Ballachulish and Onich exposures, which disposed of the still lingering miscorrelation between Appin Limestone and the cream-coloured edge of the Ballachulish Limestone. Incidentally almost, the special Glen Coe succession, both in Glen Coe and the Windows of Etive, now stood revealed as an eviscerated product due to the Ballachulish Fold-fault or Slide.

Horne and Clough came to check the new hypotheses. The latter started with the conviction that Glen Etive could not be interpreted from Callert ; but as soon as he actually saw the Callert evidence he realised that it, with the intervening mapping, left no doubt regarding the continuation of the Ballachulish Slide through the Windows of Etive. Horne, on the other hand, faced with unfamiliar rocks and ideas in steep mountainous country, suspended judgment. So Clough, left alone, took the writer to see the Windows and also his 1906 mapping from Ballachulish southwards past Loch Baile Mhic Chailein. Everywhere the evidence fitted into place.

In a first note the connection between the Callert and Etive evidence was stressed (Sum. Prog. 1909, p. 51), and promise was given of further field study. Various excursions followed, during which the Cuil Bay Slates, for instance, were added to the stratigraphical column. The most helpful trip of all was made along with Maufe in the autumn of 1909. It resulted from a conversation in which Maufe had explained to Horne that he doubted whether some of the postulated slides had been sufficiently closely located to be shown by heavy black lines on Sheet 53 which was preparing for publication. The traverse was extensive and cleared up a number of uncertainties. The most important item was the establishment of the antiformal disposition of the Ballachulish Slates that separate the Beinn Bhàn and Gleann an Fhiodh synforms (Pl. III). There soon followed a paper in the Quarterly Journal of the Geological Society (1910) entitled " Recumbent Folds in the Schists of the Scottish Highlands ".

Since then there has been one very important advance, in which the Cuil Bay Slates have been shown to be the youngest rocks of the succession listed on p. 18. This most welcome discovery was made by three young overseas visitors, T. Vogt, S. Buckstaff and O. N. Rove in 1924, though not published till 1930 (Vogt 1930 ; see also Tanton 1930, and Bailey 1930). It was based upon the reading of current-bedding in the Appin and Glen Coe Quartzites, and has in after years been abundantly confirmed.

In the 1910 paper noted above, and again in the 1916 first edition of this memoir, the present writer had emphasised that no local evidence known to him indicated whether the Cuil Bay Slates were the oldest or youngest members of the succession. In 1922, however, in a general discussion of " The structure of the South-West Highlands" he had " ventured to suggest" that they were the oldest, an inference based mainly upon " tentative " stratigraphical correlations with other districts (1922, p. 195). Naturally these correlations have had to be abandoned in the light of the discovery made by Vogt and his friends. It has also followed that the movement registered in the local schists has been towards the north-west and that the two most important fold-faults of the district, the Ballachulish and Fort William, but not the Sgòrr a' Choise, Slides, have been developed in the lower limbs of recumbent synclines (Bailey 1930, p. 81 ; 1938).

Apart from such matters as depend upon age-orientation, the writer has on occasion been able to improve in detail upon his 1910 presentation of the evidence ; and if the reader desires to follow up some particular point he will find guidance in the List of References. Here too are recorded certain criticisms under the names of G. L. Elles and C. E. Tilley (1930), J. F. N. Green (1931) and J. W. Gregory (1931)—to which replies have been given (Bailey 1934a, pp. 404, 511-522).

Leven Schists to Eilde Flags.—Let us now turn to an extensive region, roughly bounded on the north-west by a line drawn from Callert on Loch Leven to the north-east corner of the map, and on the south by the broad limestone outcrop of Lower Glen Coe and the volcanic rocks further east to Altnafeadh. The sequence, in so far as it concerns us here, is as follows :

Leven Schist—*youngest*
Glen Coe Quartzite
Binnein Schist
Binnein Quartzite
Eilde Schist
Eilde Quartzite
Eilde Flags—*oldest*

Most of the mapping of this district was done by the writer, who thought when he wrote his 1910 paper that he had proved the repetition of rock types to be due to folding. In other words he correlated the Leven, Binnein and Eilde Schists as one formation, and the Glen Coe, Binnein and Eilde Quartzites as another. The evidence, until current-bedding was called in to help, was very difficult to read ; but in spite of this R. G. Carruthers, after re-examining the whole region, successfully disentangled the true sequence (Sum. Prog. 1913 ; Carruthers 1923, pp. 25-30). The writer was given generous opportunities for further research, but for long could not reach a definite conclusion, as is explained in the first edition of this memoir (Bailey 1916, pp. 64-72) and in the memoir on the adjoining Sheet 54 (Geol.) (Bailey 1923b, pp. 30-33). At last in 1929, during a visit of the Princeton Summer School, T. L. Tanton and others demonstrated to him the trustworthiness of current-bedding. Next day the party saw the new method dispose of the old uncertainties, and posted to Carruthers a round robin carrying twelve signatures, which acquainted him of a unanimous verdict in his favour (Bailey 1930, p. 80).

This has of course, radically altered the reading of the detail of the tectonic pattern ascribed to the district outlined above. A full re-investigation was soon undertaken, and the result published in a paper entitled " West Highland Tectonics : Loch Leven to Glen Roy " (Bailey 1934a). Here we find an elaboration of a statement which was published after the Princeton excursion, namely : " The new criterion of original order of succession makes it child's play to recognise the essential structure of the district as recumbent folding, miles in extent, followed by steeply packed folding, thousands of feet in extent " (Bailey 1930, p. 81).

Two recent papers on the quartzites and mica-schists of the Loch Leven-Glen Nevis district by W. G. Hardie (1955) and G. S. Johnstone (1955) trace additional slides with the help of current-bedding.

Schist metamorphism is touched upon in the Geological Survey Annual Reports and Summaries of Progress mentioned above ; and is dealt with more fully in the first edition of this memoir and in papers by Bailey (1923a) and Elles and Tilley (1930).

Addendum.—Since the preparation of the present edition of this memoir L. E. Weiss and D. B. McIntyre (1957) have attacked the structural problems of the Loch Leven district by methods which of late have found much favour among active researchers. As a result they have reached conclusions very different from those adopted in these pages.

Weiss and McIntyre discard all reference to original stratigraphy, and pay practically no attention to structural results previously obtained—beyond speaking hazily of big recumbent folds and slides having been recognised, in part correctly. In fact, they explain that the procedure adopted up to date has been " philosophically unsound . . . because it does not include a study of structural geometry in three dimensions ". Their own main concern has been with the attitudes of bedding planes, foliation planes and fold axes, coupled with certain aspects of tectonic sequence. They divorce their observations of attitude from field and map context, grouping them instead as representative of what they consider to be tectonically homogeneous sub-areas. They next subject each group to simple geometrical analysis, and, having reassembled the resultant statistics on a vague, or one may say diluted, geographical background, they boldly draw conclusions.

Weiss and McIntyre carry their antipathy to stratigraphical control so far as to avoid any assistance from the abundant current-bedding of the district—they cover the subject with a statement that " all observations of cross-bedding made during the present investigation serve only to confirm his [Bailey's] observations ". Accordingly they do not distinguish between normal and inverted dips. A dip of 160° (French style) goes into the hat as 20° (British style) ; which presumably explains why no mention is made of the fact that almost everywhere the beds in the eastern half of their district are upside down (Kinlochleven Inversion), while those in the western half are as consistently right way up (*cf.* our Fig. 15, p. 99). As their paper is called " Structural Geology of Dalradian Rocks at Loch Leven " it is well that readers should be forewarned that its methods offer no hope of proving, or disproving, the presence of large-scale recumbent folds. (It may be retorted that Sheet 53 does not distinguish between normal and inverted dips ; but a dip on a geological map is read in its structural context, whereas a dip in a list is likely to be taken at face value.)

I may add that I have considered carefully the 85 graphs in which Weiss and McIntyre summarise their sub-areal statistics derived from thousands of observations ; and I have found nothing to suggest the desirability of change in the structural reading of the district offered in 1934 (and reproduced in the present volume). This is scarcely surprising, since both their graphs and my interpretation are based upon careful examination of identical exposures ; but it does not in itself imply that my 1934 interpretation is correct. To realise this important point one has only to remember that in 1909 I put forward a substantially different interpretation, which was, of course, just as carefully planned to conform with the data under consideration. (The 1934 corrections are based on additional evidence, furnished by current-bedding in a multitude of exposures, which distinguishes between normal and inverted successions.)

Before attempting to read the remainder of this addendum anyone unfamiliar with the subject should look through chapters iii, v, vi D, vii and viii in conjunction with Sheet 53. He will then realise that the Aonach Beag and Ballachulish Cores, north of Loch Leven, have been for a long time interpreted as refolded at a relatively late date into four secondary synforms (Fig. 17, p. 112). The Ballachulish Core is preserved in the three more south-easterly of these synforms, which are shown in more detail in Fig. 8, p. 50. All three, pitching[1] S.W., cooperate to develop the great pitch-depression of Glen Creran south of the loch (Fig. 17). That these three synforms, and, along with them the Glen Creran Pitch-Depression as a whole, are later than the formation of the Ballachulish Core is emphasised by their folding of the Ballachulish Slide as a pre-existent structure.

The most south-easterly of the three synforms may be named for ready reference the Mam na Gualainn Synform—it is No. 1 Fold of Weiss and McIntyre (1957, p. 590). To the south-east it is succeeded by what has been interpreted in the past as a complementary antiform with blunt crest pitching very steeply S.W. under lower Glen Coe—where it mightily increases the scope of the Glen Creran Pitch-Depression. This S.W.-pitching antiform may be called the Loch Leven Antiform. It is replaced in Weiss and McIntyre's interpretation by a very different structure, their No. 2 Fold (1957, p. 590).

This has brought us to a crucial difference of interpretation concerning the contrasted attitudes of the Glen Coe Quartzite north and south of Loch Leven (within a couple of miles of Invercoe). On the north the dip is steeply N.W., whereas on the south it is steeply S.W.

Bailey.—The N.W. dip N. of the loch corresponds with the N.W. limb of the Loch Leven Antiform. The S.W. dip S. of the loch corresponds with the S.W. pitch of the blunt front of this antiform.

Weiss and McIntyre.—The N.W. dip is a pitch-dip shown by the upper limb of the Loch Leven (No. 2) Fold, reinterpreted as a recumbent fold striking N.W. The S.W. dip corresponds with partial exposure of the hinge of the same, supposedly recumbent, Loch Leven Fold.

Both interpretations accept the view that there are two phases of folding involved ; but even here there is local disagreement :

Bailey.—The Mam na Gualainn Synform and the Loch Leven Antiform, both belong to the later phase, since both fold the Ballachulish Slide.

Weiss and McIntyre.—The Mam na Gualainn Synform is relatively late because it strikes S.W. and observation often shows S.W.-striking structures crossing earlier structures that are otherwise oriented. The supposedly recumbent No. 2 Fold striking N.W. is relatively early.

One is left with the impression on reading Weiss and McIntyre that they recognise sliding as omnipresent, but that they do not think of the Ballachulish Slide as a definite structural entity that can be traced through later folds—they do not even allude to its possible existence ! I must leave readers to form their own judgment in this matter and to ponder on the consequences.

As a connected issue it may be pointed out that there are two opinions regarding other irregularities of strike that are characteristic of the Loch Leven district away from the immediate neighbourhood of Invercoe :

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[1] See p. 34 for definition of pitch.

Bailey.—These irregularities are mostly relatively late date diversions dependent upon the development of the Glen Creran Pitch-Depression.

Weiss and McIntyre.—These irregularities are relatively early residuals from a phase of recumbent folding with N.W. strike.

Let us pass on. In the first description given of the district (Bailey 1910, p. 604) we find the following :

" The secondary folding of the Aonach Beag Core has been accompanied by production of a very striking vertical strain-slip cleavage, which affects a belt of country about a mile wide [a later account adds that it is conveniently exposed in Glen Nevis gorge]. The strain-slip cleavage cuts and displaces quartz-veins in the schists which it traverses, ... it would seem that the quartz-veins in the present instance were formed in connexion with the development of the Aonach Beag Core and were buckled and broken when the latter suffered its subsequent corrugation ".

The temptation was resisted to extend this conclusion to cover a wide area, and to distinguish between foliation phenomena connected with the development of the great recumbent folds (which latter may themselves be far from contemporaneous) and others connected with the subsequent development of the Glen Creran Pitch-Depression. Need for caution was emphasised by failure to find in the West Laroch quarries, or in the exposures further south, any criterion of attitude which would preferentially allot the cleavage of the Ballachulish Slates there displayed either to the movement responsible for the Ballachulish Slide or, alternatively, to that responsible for the Glen Creran Pitch-Depression—it is probably a very mixed phenomenon.

Weiss and McIntyre have given much more attention than I have to this difficult subject, and have decided that the Loch Leven district furnishes a widespread record of two main phases of foliation development. I am much impressed by their findings, and am prepared to attach the two phases of Aonach Beag to their time-scale. The Aonach Beag phenomena are exactly similar in appearance to the Loch Leven phenomena illustrated in photographs by Weiss and McIntyre (1957, pl. 2).

I must, however, add one more word of caution. Weiss and McIntyre think, probably quite rightly, that the early foliation of the district is accompanied by, and sometimes " recumbently folded " into, little " B-folds " that are apparently syngenetic" (1957, p. 579). These foldlets they illustrate in three photographs (1957, pl. 1). I think the following is a fair description. In one photograph, lettered D, the foldlets reproduce miniature Jura-Mountain structures, the whole tilted. In another, C, the foldlets are compressed parallel with the regional early foliation, and are disposed as typical dragfolds with orthodox relation to larger, but still very small, antiforms and synforms. In still another, A, the hinges of the foldlets are only seen occasionally, and the tightly appressed limbs are inseparable from the accompanying early foliation.

The point which two of these photographs, and also the accompanying text, quite clearly makes is that the B-foldlets tend to be parallel with the regional, early foliation ; and everybody knows that the early foliation of the district is very variously inclined, generally at steep angles. Accordingly to speak of these foldlets as " recumbent " is to use the word " recumbent " in an unusual sense ; and to argue from their presence that large-scale " recumbent " folds are to be expected in the district is apt to confuse the unwary. (The obvious retort is that the main fold of the district, the Kinlochleven Recumbent Anticline, has already been described as recumbent in spite of the obvious abundance of steep dips.

The answer is that this fold is an up-and-down structure ; it is recumbent only on a very large scale ; it is steep in its smaller, but still large, ups and downs. For instance, in its widely spread inverted limb, the Kinlochleven Inversion, all antiforms have cores of younger rocks, and all synforms have cores of older rocks. This signifies very large-scale inversion, and therefore very large-scale recumbent folding ; but the limb-dips of the antiforms and synforms are generally steep, vertical or even reinverted.) See also King and Rast (1959).

IGNEOUS ROCKS

Early Work.—Between 1810 and 1820 the presence of " granite " at Ben Nevis, Glen Coe, Ballachulish and the Moor of Rannoch, and of associated " porphyry " (now known to be lavas and ashes) at the two first-named localities, had been reported by J. Williams (1810, pp. 409, 469), R. Jameson (1811, p. 115), T. Macknight (1811, pp. 307-357 ; 1821, pp. 113-5), J. Macculloch (1817) and A. Boué (?1820, pp. 21, 66-7). Williams at Ben Nevis, standing on the " granite " floor of the Allt a' Mhuilinn corrie, and looking up at the great cliff of " porphyry " reaching to the summit of the mountain (Pl. X), naturally, though mistakenly, thought that the " granite " passed under the " porphyry ". We have already seen how the Wernerian Macknight agreed with this interpretation, and how, at first, he extended it outwards, thinking that the surrounding schists passed in turn under the " granite ". Macculloch's Huttonian observations on contact-metamorphism and schist-inclusion by the Ballachulish " granite " have also been noted.

The structure of Ben Nevis was wonderfully clearly appreciated by C. von Oeynhausen and H. von Dechen (1830 ; 1834). They saw that the " granite " " has forced its way through [the schists] : the granite traverses these also, in the form of veins." Moreover they considered it " fully established " that the shape of the " porphyry " making the mighty cliff above Allt a' Mhuilinn " is that of an oblique four-sided pyramid, irregular and truncated, rising on the east and south, *through* the granite ; and not merely overlying it, as M. Boué supposed ". This constituted a thoroughly good field-appreciation of shape, though now one would say four-sided prism with rounded angles rather than pyramid. Bryce, it may be added, also closely followed the junction between lavas (he called them greenstone instead of porphyry) and " granite " at Ben Nevis. He did not rightly appreciate the mutual relations of the two rocks, but he did notice " in places portions of siliceous slate, sometimes of conglomerate structure entangled in the greenstone, or dividing it from the granite " (1864, p. 105). He was probably referring to a strip of schist and basal breccia that is exposed between the lavas and the " granite " on the corrie floor of Allt a' Mhuilinn.

Passing to Glen Coe, we find W. Stevenson giving a fairly accurate account of phenomena of permeation which are there locally important. " Near the granite and porphyry," he writes, " where the metamorphism becomes extreme, flesh-coloured felspar is added chiefly between the slaty and quartzose laminae " (1867, p. 167). The value of this description is much reduced by the extravagance of some of the accompanying speculations.

In 1874 J. W. Judd wrote an account of the " Newer Palaeozoic volcanoes " of the Highlands (1874, p. 276). He pointed " to the very marked similarity in petrological characters between the vestiges of the lava rocks preserved in Beinn Nevis and Glen Coe on the one hand, and those which make up the large areas, as of Lorn and central Scotland on the other " (1874, p. 295) ; and by " lava rocks,'' he meant the '' porphyry '' or '' greenstone '' of earlier authors, which he had no hesitation in recognising as lavas and agglomerates.

Most of the Newer Palaeozoic volcanoes of central Scotland are shown by fossiliferous associates to be of Old Red Sandstone and Lower Carboniferous date ; and Judd prefers not to make any closer approximation in regard to the lavas of Lorne, Glen Coe and Ben Nevis. A strange misstatement may be noted in this connection. Judd says '' in the map of Scotland published in 1861 [it is dated 1862] by Sir R. Murchison and Prof. Geikie the ' traps ' of Lorn are indicated as being of Old Red Sandstone age '' (1874, p. 277). Actually this map miscorrelates the Lorne traps with those of the Hebrides, and groups both as Oolitic. Geikie's map of 1876 does show the Lorne lavas as of Upper Old Red Sandstone age, but this was two years after Judd had published his paper. The matter was finally settled by the finding of Lower Old Red Sandstone fossils in Lorne by A. Macconochie (Geikie 1897b). Stems and a *Pachytheca* were later found in Glen Coe by D. Tait and B. N. Peach (Sum. Prog. 1903, pp. 78, 130). They were for some years referred to known Lower Old Red Sandstone types ; but redeterminations have since rendered their age-significance less definite (p. 145).

Judd interpreted the great '' granite '' masses of our area as the eroded stumps of mighty volcanoes, a view that may come very near to the truth. He also, like others previously, called attention to the multitude of dykes characteristic of parts of the region. He clearly recognised that the '' granites '' had been '' protruded '' through the schists. At Ben Nevis, however, he repeats Williams' structural mistake, for he thinks that the lavas and agglomerates furnish a '' great cap '' to underlying '' granite ''—and this in spite of his knowledge of von Oeynhausen and von Dechen's claim that the '' masses of ' porphyry ' had been forced through the midst of an earlier-formed mountain of granite '' (Judd 1874, pp. 293-4). All the same, a plug, or neck, theory of the centrally exposed volcanic rocks continued popular until Maufe in 1910 cleared up the whole matter. It is illustrated, for instance, in sections accompanying Geikie's geological map of Scotland, both in 1892 and 1910. On the other hand Ben Nevis is not mentioned in Geikie's '' Ancient Volcanoes of Great Britain '' (1897a), and the Glen Coe lavas are briefly dismissed as '' picturesque outliers '' of the Lorne series. All this goes to show how little was known of the structure of the district when the Geological Survey undertook its detailed investigation.

Meanwhile, between 1874 and 1910, the volcanic character of the central rocks of Ben Nevis was emphasised by descriptions of hornblende-andesite (Teall 1888, p.287, pl. 37, 1) and of fine tuff (Mackie 1907). Teall's description of the Ben Nevis hornblende-andesites, given in his '' British Petrography '' (1888) established '' the only good instance of a hornblende-andesite known in the British Isles '' up to date ; though now the type is widely recognised from Glen Coe and elsewhere.

Teall also referred in '' British Petrography '' to the Ballachulish and Ben Nevis '' granites '' and to an unusual '' plagioclase-augite-olivine-mica rock '' at Kentallen, west of Ballachulish (1888, pp. 268, 325, pl. 16, 1). The Ballachulish '' so-called granite '' is carefully described as illustrating the great difficulty of drawing a line between quartz-mica-diorites and granitites.

Geological Survey and Later.—As for the Kentallen rock, Teall did not in 1888 recognise its orthoclase ; but later, when as Petrographer of the Geological Survey he examined specimens collected by Wilson, he drew special attention to the presence of this mineral and enriched a full description of the rock with a chemical analysis. He further made comparison with Brögger's olivine-monzonite type, though careful to point out that the Kentallen quarry rock " is far richer in olivine than any rock hitherto recognised as belonging to the monzonite group " (Ann. Rep. 1897, pp. 22-3). Teall's notes in the Annual Report of the Geological Survey for 1896 and in Summaries of Progress for 1897 to 1899 furnish a much abbreviated record of the foundations he laid for future petrological work on the plutonic rocks and the associated contact-metamorphism of the district. As an obvious superstructure we may note a very able paper by J. B. Hill and H. Kynaston introducing the name kentallenite as soon as it had become apparent that the Kentallen type reappeared at a number of widely separated localities in Argyll (1900).

Kynaston entered Sheet 53 (Geol.) after mapping Lorne lavas and Cruachan " Granite " in Sheet 45 (Geol.) to the south ; and he undertook much of his own petrology as he went. In Sheet 53 he mapped a considerable part of the Glen Coe lavas and of the northward extension of the Cruachan " Granite," which latter he found to intrude and bake the lavas (Sum. Prog. 1901, pp. 82-3). Before leaving Sheet 45 he had already established two main features closely affecting the geology of Sheet 53, namely : the presence of what is now called the Etive Swarm of parallel north-east dykes (Sum. Prog. 1898, p. 88) ; and the fact that the Cruachan " Granite " is pierced by a central, more acid granite—called after Glen Etive by Kynaston, but later renamed after Ben Starav (Sum. Prog. 1899, pp. 78, 80). He pointed out that this Starav Granite is apparently (we now know really) later than the Etive Swarm.

Kynaston's year by year descriptions include certain structural mistakes, but these are mostly cleared up in a note to the British Association meeting of 1902. Here we find a statement of what is still accepted as the standard succession of the Glen Coe volcanics (basic andesites, rhyolites, agglomerates and hornblende-andesites, Fig. 20, p. 133) and also a recognition of eastward overlap in this succession upon the schist floor. Further, while rightly maintaining that the Cruachan " Granite " intrudes the Glen Coe lavas, he records the presence of boulders of granite and diorite, from some other source, in the basal conglomerates of the Glen Coe volcanic pile (1903).

The above announcements were amplified in manuscript notes left by Kynaston on his departure for South Africa in 1903—notes that were later incorporated in the first edition of this memoir. Moreover, these notes include a first description of the boundary-fault of the Glen Coe cauldron as exposed in An t-Sròn (Fig. 20). Kynaston could not, of course, foresee that the fault he mapped in An t-Sròn would presently be found to turn round and encircle a sunken area ; but he did realise, so far as was possible from a single section, the fundamental relation existing between it and the An t-Sròn " Granite," which is part of what has since been called the Fault-Intrusion. The following is taken from his manuscript :

> " On the south side of Glen Coe, south-south-west of Loch Achtriochtan, a well-marked line of fault, indicated by a deep cleft on the north-east slopes of An t-Sròn, cuts off abruptly the andesites which are seen on the east side. On the west side occurs a mass of granite which shows a marginal facies along the line of the fault, so that it is possible that the fault may be older than the granite ".

Although we now claim that faulting and intrusion were contemporaneous, it remains true that at any particular point the fault must have started before the first arrival of magma.

Kynaston's mapping of the Glen Coe lavas was in the main completed by Maufe, as also his mapping of the Boundary-Fault, usually in two branches, in its course between An t-Sròn and Glen Etive. South of Glen Etive, Clough traced a branch of the Boundary-Fault with flinty crush-rock along it, which latter he compared with flinty crush-rock he had already brought to notice in the Cheviot Hills and in the North-West Highlands (Sum. Prog. 1905, p. 68). This observation was soon to be extended along much of the line of the Glen Coe Boundary-Fault elsewhere.

North of An t-Sròn Maufe and Peach traced the Boundary-Fault past Loch Achtriochtan to near the west end of Aonach Eagach (Fig. 19, p. 132). It was not realised at the time that the fault here suddenly turns through a right angle ; in fact Peach, on finding a contact of quartzite and lava at the east end of Aonach Eagach, attributed it to unevenness of the floor upon which the volcanic rocks had accumulated (Sum. Prog. 1904, p. 70). Yet it was clearly recognised that the fault was definitely arcuate, running N.N.W. from Glen Etive, N. at An t-Sròn and N.N.E. past Loch Achtriochtan to Aonach Eagach.

While Maufe was working on the volcanic rocks from Clachaig Hotel, the writer, stationed at Caolasnacon and later at Altnafeadh, was assigned the predominantly schistose country to the north and north-east. This by accident led to my mapping the boundary-fault for the six miles between Aonach Eagach and Stob Beinn a' Chrùlaiste beyond Altnafeadh, thus virtually completing the main Glen Coe story (Sum. Prog. 1906, pp. 96-8, fig. 2).

Two facts of historical importance may here be introduced. The first belongs to the very outset of my investigation, when Maufe explained to me that he had already found that the quartzite-lava contact at the east end of Aonach Eagach (ascribed by Peach to an irregularity of the pre-lava floor) was really due to an abrupt turn of the Boundary-Fault. To this Maufe added that his experience between Glen Etive and Aonach Eagach assured him that the Boundary-Fault, when followed eastwards, would be found again and again flanked exteriorly by Fault-Intrusion, smoothly chilled against it. I answered that, if all this proved true, we must be dealing with a cauldron-subsidence, around which magna had contemporaneously spurted up. The phrase ' cauldron-subsidence ' was used because of Suess' descriptions, as rendered in the English translation of his " Antlitz der Erde," of the Ries and Höhgau cauldrons, at first interpreted as regions of subsidence (Suess 1924, index references).

The second point to be noted came after I had almost finished the mapping of my share of the fault-zone, and was leading Clough and Maufe along its course. On coming to Stob Mhic Mhartuin, in some ways the type exposure of the Boundary-Fault (Pl. IX), Clough noticed that I had overlooked a one-inch layer of flinty crush-rock immediately adjoining the chilled margin of fault-intrusion. This proved to be Clough's major contribution to the study of the Glen Coe Cauldron ; for recognition of flinty crush-rock at a number of other places enabled me to improve materially my understanding of exposures in my own ground, and, in company with Grabham, to continue with certainty the tracing of the boundary-fault from Stob Beinn a' Chrùlaiste to Coire an Easain (Fig. 29, p. 164). In this eastern district, it may be added, Grabham made the independent very important discovery that the Moor of Rannoch " Granite " is earlier than the Fault-Intrusion of Glen Coe.

The standard account of " the Cauldron-subsidence of Glen Coe and its Associated Igneous Phenomena " is by Clough, Maufe and Bailey (1909), and to this readers are referred. Among other things they will find in it the first suggestion that some plutonic intrusions occupy subterranean cauldron-subsidences (1909, fig. 14, p. 670), and also the first explanation offered of swarms of parallel dykes

(1909, pp. 673-5). It may be added that subaerial calderas of subsidence have been claimed at a number of modern volcanoes from very early days of geological interpretation ; but Glen Coe probably affords the first deeply eroded example to be thoroughly appreciated. It should, however, be recalled that J. Schetelig, at about the same time as the Geological Survey was working in Glen Coe, independently investigated similar instances in the Oslo district—he briefly mentions the Baerum caldera in an excursion guide of 1916, but he died in 1935 without having published anything that might be called a description (*cf.* Holtedahl 1943). It would take too long even to list papers on similar subjects that have since appeared at home and abroad.

Maufe went from Glen Coe to Ben Nevis, where he found the same general style of intrusion-tectonics, though with interesting variations. His standard account is entirely his own work (Sum. Prog. 1910). It has been modified by J. G. C. Anderson (1935b) in relation to the marginal portion of what Maufe had separated as the Outer " Granite," but otherwise remains intact.

Anderson (1937a) has also published a very important paper on the Etive Complex (including the Cruachan, Starav and other " Granites ") ; but his new conclusions mostly concern Sheet 45 (Geol.). In addition T. R. M. Lawrie has subdivided the Ballachulish Pluton as shown in the 1940 and 1948 editions of Sheet 53.

Anderson's papers on Ben Nevis and Etive carry valuable petrographical data, especially in regard to gravitational differentiation ; while two by F. Walker (1924, 1927) are concerned with various intrusions in the neighbourhood of Kentallen. Moreover, as might be expected, the rocks of the district figure prominently in modern textbooks of petrology.

Two more petrological papers may be selected for special notice, for though they deal with the geochemistry of the Devonian (or Caledonian) rocks of Scotland as a whole, these rocks are better represented in Sheet 53 than anywhere else. The first supplies a comparison of the major constituents of the Devonian rocks with those of their neighbours of Carboniferous and Tertiary age. It establishes, among other things, a relatively high content of MgO (Elder 1935). The second concentrates on trace elements, a field that has been but little explored (Nockolds and Mitchell 1948). See also Nockolds and Allen (1953 ; 1954).

Great Glen Fault

A wonderful claim has been put forward by W. Q. Kennedy (1946) that the Great Glen Fault, along which Loch Linnhe has been eroded, is a sinistral wrench- or tear-fault with a horizontal displacement of 65 miles. The evidence for the most part lies outside Sheet 53 (Geol.), but will be summarised in chapter xxi.

Glaciation and Recent Deposits

Reference to the bibliography of this Memoir will show that the Boulder Committee of the Royal Society of Edinburgh from 1878 to 1884, under the convenorship of David Milne Home, issued several reports, which touched upon its glaciology. It is interesting to find that kentallenite and augite-diorite boulders in Glen Creran, and along the shore south from Kentallen, early attracted attention. At the time there was a great tendency to look for a westerly or north-westerly source for all erratics, and accordingly specimens of the " black granite " boulders were dispatched to Prof. Judd for identification with the gabbros of Mull ; it is not surprising considering the date, 1877 or 1878, that Prof. Judd considered it " certain they were derived from the Western Isles ".

On general grounds this conclusion was immediately disputed by James Geikie (1878, p. 867), who stated that he had never seen Hebridean erratics upon the mainland of Scotland. In fact, local evidence might have been adduced to throw doubt upon the suggestion, for, thirty years before, Charles Maclaren (1849, pp. 169-172) had illustrated a masterly account of the glaciation of Scotland by a detailed description of certain conspicuous *roches moutonnées* at Ballachulish, and had shown, it now seems conclusively, that these rocks had been moulded by land ice moving from *east to west*.

M. F. Heddle (*in* Boulder Com. 1880b, p. 630) strengthened James Geikie's position immensely by finding kentallenite or, as he described it, a rock " identical in composition with the boulders," occurring *in situ* above the path which leads between Glen Creran and Ballachulish, a couple of miles north of Salachail. In spite of this discovery, however, the idea that the " black granite " boulders came from Mull was not finally relinquished for years. It is now known, of course, thanks to Grant Wilson's mapping and the petrographical descriptions of Teall, Hill, and Kynaston, that " black granite " (kentallenite and augite-diorite) is represented by several outcrops in the district, and that it has an individuality of composition which entirely distinguishes it from the Tertiary gabbros. This later work is dealt with in chapter xvii.

It may be stated that, although ice-rafts are frequently invoked by the reporters of the Boulder Committee, many of the phenomena of transport were correctly attributed to local glaciers, especially in the later reports. Colin Livingston of Fort William and Heddle were both particularly clear on this point.

While dealing with the subject of erratics, it is convenient to direct attention to a pebble found by J. Currie in far-away Iona, since he claims that it has been transported by ice from Glen Coe (1899). One of the lavas of Glen Coe contains a beautiful red epidote, first found by H. Witham in 1824 and described, under the name " withamite," by D. Brewster (1825). The Iona erratic is said to be identical with this Glen Coe lava, both in its general characters and in its containing a considerable quantity of withamite. It is quite probable from the direction of ice flow that Currie is right in deriving this pebble from Glen Coe, sixty miles distant, but it also seems possible that it may have come from some unknown source in Mull ; this possibility is suggested owing to Harker's description of rosy epidotes which " may be termed withamite " occurring in some of the lavas of Skye (1904, p. 52).

An analysis of the Glen Coe withamite has been given by Thomson (1836, p. 377) and another, much more complete, by Heddle (1898, p.355).

The raised beaches of the district have not attracted very much notice. R. Chambers (1848, p. 92) has referred to them, and has figured the problematical terraces of Corran (wrongly called Connel in his description).

J. Gwynn Jeffreys (1863) has also published an exceedingly valuable list of fifty-nine marine species of Scandinavian facies from a bed found by Captain Bedford at Fort William. The significance of these shells, and of certain mosses found by Wright and Maufe beneath the " 25-ft beach " of the same locality, and described by H. N. Dixon (1910), will be discussed in chapter xxii.

Although not rich in lakes the district has shared in the advantages of the great Scottish fresh-water loch survey, carried through under the direction of John Murray and Laurence Pullar during the years 1897 to 1909. The results have been published in collected form (1910), and a reference to the bibliography of this memoir will enable the reader to find details regarding six small lochs which have been sounded in Sheet 53. E. B. B.

CHAPTER III

FORMATIONS AND TERMS

TABULAR STATEMENT OF FORMATIONS

THE following classification has been adopted in the index of Sheet 53 :

POST-GLACIAL

Peat
Landslips

GLACIAL AND POST-GLACIAL

- Fresh-Water Alluvium :
  - Lowest Terrace
  - High Terrace
  - Higher Terrace
  - Alluvial Cone
  - Fluvio-glacial Gravel (only separately mapped at Corran)

POST-GLACIAL

- Marine Alluvium :
  - Present Beach
  - Low Raised Beach
  - " 25-Ft " Raised Beach, about 35 ft above O.D.
  - Raised Marine Deltas
- Raised Sea Margins are also shown

GLACIAL

Morainic Drift

Boulder Clay

TERTIARY AND DOUBTFUL

Dolerite Dykes, mostly N.W. or W.N.W.

Monchiquite W.N.W. Dyke (Glen Coe) } (treated as Permian in the sequel)
Breccia Vent with Nepheline Basalt (Allt Coire na Bà) } (treated as Permian in the sequel)

DOUBTFUL MIDDLE OLD RED SANDSTONE

Rudha na h-Earba Conglomerate

LOWER OLD RED SANDSTONE AND DOUBTFUL

- Sediments :
  - Conglomerates, Sandstones, and Shales
- Minor Intrusions :
  - Porphyrite Dykes, mostly N.E. (some with slight foliation near Starav Granite are distinguished by a symbol)
  - Fine-grained Diorite N.E. Dykes, sometimes porphyritic (Glen Etive District)
  - Andesite W.N.W. Dykes (Glen Coe District)
  - Lamprophyre Dykes and Sheets
  - Quartz-Porphyry, Felsite, and Rhyolite Dykes
- Plutonic Intrusions :
  - Biotite-Granite, Porphyritic Granodiorite and Tonalitic Granodiorite of the Morvern-Strontian Complex
  - Granite and Quartz-Diorite, including much of the " Fault-Intrusion " of Glen Coe
  - Porphyrite Facies of " Fault-Intrusion "
  - Porphyrite Facies of " Early Fault-Intrusion "
  - Augite- and other Diorites, including two outcrops of " Early Fault-Intrusion " at east margin of map
  - Kentallenite and Cortlandtite
- Contemporaneous Igneous Rocks :
  - Agglomerates, including some Sedimentary Breccias
  - Rhyolite Lavas
  - Andesite Lavas separated locally into Hornblende- and Augite-Andesites (including Basalts)

METAMORPHIC ROCKS OF UNCERTAIN AGE NORTH-WEST OF LOCH LINNHE

Stratigraphical Relations of the Sediments are doubtful

Intrusions :
- Epidiorite and Hornblende-Schist (much of the Glen Scaddle intrusion might be classed as Diorite)
- Augen Gneiss (Sgùrr Dhomhnuill) ; see p. 116

Of mixed Origin :
- Felspathised Sedimentary Gneiss

Sediments of " Moine Series " :
- Limestone
- Quartzite
- Psammitic Gneiss
- Pelitic Gneiss

METAMORPHIC ROCKS OF UNCERTAIN AGE SOUTH-EAST OF LOCH LINNHE

Intrusions :
- Hornblende-Schist (S.E. of Glen Creran) probably later than main folding

Sediments in Stratigraphical Sequence from Cuil Bay Slates (youngest) to Linnhe Quartzite (oldest) :
- Cuil Bay Slates (with Lismore Limestone of Shuna probably younger still, but not indexed)
- Appin Phyllites and Limestones
- Appin Quartzite
- Ballachulish Slates
- Ballachulish Limestone
- Leven Schists
- Glen Coe Quartzite
- Binnein Schists
- Binnein Quartzite
- Eilde Schists
- Eilde Quartzite
- Eilde Flags (with Linnhe Quartzite and Dark Schist)

Sediments near Blackwater Reservoir, of doubtful Stratigraphical Position :
- Stob Quartzite
- Reservoir Schists
- Reservoir Quartzite
- Reservoir Flags

MINERAL VEINS

Haematite (E.N.E. of Glenure House) ; see also p. 288

In addition to giving the position of the various rock groups, the map carries signs to show how the inclination of the bedding and cleavage, or foliation, of the sedimentary and schistose rocks varies from place to place. Faults and slides (fold-faults) are distinguished from unbroken junctions, while a device is employed in certain cases to indicate which of two adjacent igneous intrusions is the later. Glacial striae are indicated by special arrows pointing in the direction of ice-flow.

DISCUSSION OF TERMS

Highland Schists.—A bed or formation is said to *young* in the direction towards which it presents its younger side. An uninverted bed youngs upwards and in the direction of dip ; but an inverted bed youngs downwards and away from the direction of dip. The direction of younging is often determinable from current-bedding (Fig. 13, p. 92).

The folding of the schists within Sheet 53 is extremely complex, and it may be helpful to explain the terminology employed in its description. The idea of an *isoclinal fold* is sufficiently familiar to form a starting-point. In an isoclinal fold the two *limbs* of the fold and the intervening *axial plane* of the same have assumed a rough parallelism, for a lesser or greater distance ; the inclination of the parallel limbs we take as defining the *inclination of the fold* itself ; and experience teaches us that the isoclinal folds of some of the better known mountain chains often lie at low angles, and such prostrate folds are said to be *recumbent*.

Recumbent folds, where well-developed, frequently attain to surprising dimensions, and can be traced for miles as more or less flat sheets in a direction at right angles to the strike of the folding. These large-scale folds generally occur in groups, in which the apices of the recumbent anticlines all point in one direction and the apices of the complementary synclines in the opposite direction. The direction in which the apex of a fold, whether anticline or syncline, points, defines the direction in which that particular fold *closes*. In the other direction the fold is said to open or *gape* (*cf.* fold of Glen Coe Quartzite, Fig. 9, p. 51, which closes to the N.W. and gapes to the S.E.).

When we deal with a region unaffected by recumbent folds it is easy to define an *anticline* as a fold that *closes upwards*, or what is the same thing under the circumstances as a fold with a *core of older formations* (and a *syncline*, *vice versa*). When, however, we enter a region affected by recumbent folding we get into difficulties. This is partly because the axial plane of a recumbent fold may undulate, so that we may find a recumbent anticline closing upwards at one locality and downwards at another. At the same time, if the recumbent folding has affected strata previously uninverted, it remains true that a *recumbent anticline* contains a core of older formations—and, as always, *vice versa* for a *recumbent syncline*. For example, we are reasonably certain that the main recumbent folds of Sheet 53 were not preceded by regional inversion. Accordingly, once we learnt that the cores of the great *homologous* Ballachulish, Aonach Beag and Appin recumbent folds consist of younger formations, we accepted them as recumbent synclines separated by complementary recumbent anticlines (Fig. 17, p. 112).

Another difficulty is that later, often called *secondary* folds, which for convenience we shall assume to be non-recumbent, frequently affect earlier recumbent folds. Where such secondary folds involve an inverted recumbent limb they will close upwards, if they possess a core of younger formations, and downwards *vice versa*. Altogether, it is sometimes helpful to call a fold which closes upwards an *antiform* rather than an anticline, if one wishes to state its form without fear of suggesting that its core consists of older formations. *Synform* is the complementary term. It is interesting to recall that the Appin recumbent fold, where its core outcrops between Glen Nevis and Onich (compare one-inch map with Fig. 2, p. 37) was recognised as a synform long before relative dating of its affected formations proved that it has a core of younger rocks.

Sometimes, where an isoclinal fold crosses a cliff, the natural section provides a clear picture of the direction of close. This is the happy position where the Appin Fold, just mentioned, is sectioned by the steep south-western face of Glen Nevis (Fig. 3, p. 39). The view from near Glen Nevis House shows that the fold has here a core of Ballachulish Slates clearly resting upon the purer part of the Ballachulish Limestone.

Observation is rarely such an easy matter. Isoclinal folds, where strictly recumbent, close towards some point of the compass without any upward or downward component, so that for them the words antiform and synform have no application. Of course, strictly recumbent folds do not occur on a large scale in nature ; but the uncertainties introduced by undulation of the axial plane have already been noted.

Even in non-recumbent folds the determination of upward or downward close may present difficulty in the field, for topographic assistance such as is provided in Glen Nevis, is rarely forthcoming in Scotland.

It is often helpful to limit the use of the word *core* by assigning to it an arbitrary stratigraphical boundary. In the unlimited sense, any fold, wherever found, has an inner portion of which we have already spoken as the *core*, and a corresponding outer portion which may be called the *envelope*. As folds close towards a particular direction, formations furnishing envelope at one place must function as core at another, and *vice versa*. If, however, we consider a fold in its entirety, we can give its core a statigraphical limit and a correspondingly definite name. This procedure has been adopted in the sequel in regard to the recumbent synclines of Ballachulish, Aonach Beag and Appin. The *Ballachulish*, *Aonach Beag* and *Appin Cores* are defined as the cores of these three synclines *in so far* as they consist of Ballachulish Limestone (with or without later formations). The older formations, Leven Schists, etc., involved in the folding, are then classed as envelope. Over wide areas the envelope formations must of course occupy core positions, but this involves no logical contradiction. Also it need lead to no confusion, for it is easy to drop the limited-core terminology wherever it ceases to be convenient.

An even more important term is *fold axis*, though it happens that it can only be given an approximate definition unless the particular fold has a well marked apex or angular close or hinge. Where such an apex affects a bed, the fold axis for that bed follows the line of the apex. While there is generally some looseness in the definition of a fold axis, *axial direction* is what really matters, and it is unambiguous in an ideal cylindroid fold. It is in fact the one direction shared by all positions of the folded bed. In other words, it is the direction along which any two non-parallel positions of this bed will intersect if produced. The inclination of the axial direction of a fold is what is called in the index of Sheet 53 the *pitch* of the fold. This practice is followed in the present memoir although, of recent years, the word *plunge* has to a large extent replaced pitch in this sense and pitch has been given a different meaning.

As a working rule we may treat dips as giving pitch if they are observed along the axial belt of a fold outcrop and if they are directed roughly parallel with the general strike of the fold. If the core disappears under the envelope in the direction of pitch, then clearly the fold is an antiform, and *vice versa* in the case of a synform. Search for information is helped by the fact that large and small folds in any particular district often have the same direction of pitch—but this cannot be taken as a universal rule.

Pitch may in certain cases be deduced. We have seen that a natural cross-section of the Appin Fold at Glen Nevis shows that the fold there is a synform. A glance at the behaviour of outcrops to the south-west as far as Onich allows us to deduce that the pitch of this synform is south-westwards.

Now, as may readily be imagined, the rocks included in recumbent folds have very commonly broken. The immense extent of many of these folds is due, in large measure, to the rupture of the folding rocks, and their displacement along *fold-faults* or *slides*, which as a rule lie approximately parallel to the folds themselves. Slides do not belong all to one category. Some are developed in, and more or less replace, the lower, reversed limbs of anticlines ; these are known as *thrusts*. Others are developed in, or replace, the lower unreversed limbs of synclines, and are called *lags*. Thrusts and lags are complementary to one another in the sense that anticlines and synclines are said to be complementary. When Sheet 53 was mapped the order of stratigraphical succession had not been discovered. All that could be said was that the slides of the district included examples of both thrusts and lags, and that it was impossible to say which were which.

When the stratigraphical succession was determined it was surprising to find that the two most prominent slides of the district, the Fort William Slide in the lower limb of the Appin Fold (Fig. 2, p. 37) and the Ballachulish Slide in the lower limb of the Ballachulish Fold (Figs. 8, 9, pp. 50, 51) are both lags. This is surprising, because thrusts are much better known in other parts of the world and are much easier to picture in course of development. The lags of our district are associated with unusually extensive unthinned inversions.

Before leaving this subject it is interesting to recall that, when the recumbent fold paper (Bailey 1910) was presented at the Geological Society, *slip* was used as a short synonym for *fold-fault*. This was, however, exchanged for *slide* at the request of Charles Lapworth, who had originally used slide in the sense that thrust is now employed in descriptions of the North-West Highlands.

Igneous Rocks, Etc.—The term *pluton* is freely used in the sequel, because of its convenient vagueness, to denote a mass of coarse-grained igneous rocks, irrespective of composition or shape. Thus the Ballachulish Pluton south of Ballachulish Ferry is half quartz-diorite, half granite.

It has already been explained (p. 28) how the *Cauldron-Subsidence* of Glen Coe came by its name. The investigation of this occurrence supplied a group of ideas which, in English, are rendered by such terms as *ring-fracture*, *ring-fault* and *ring-dyke* ; but the actual introduction in our country of ring-terminology awaited the recognition of Glen-Coe-like ring-features in the Tertiary volcano of Mull (ring-bosses, Bailey *in* Sum. Prog. 1914, p.51 ; ring-dykes, Bailey and Richey *in* Sum. Prog. 1915, p. 36). T. Thoroddsen, however, had already drawn attention to ring-fractures, or as he called them "*Kreisbrüchen*", in Iceland (for a review *see* Bailey 1919). The Glen Coe ring-fault is very often spoken of as the *Boundary-Fault* of the Cauldron-Subsidence. At some localities it has more than one branch, and movement along it can sometimes be shown to have been intermittent.

Flinty crush-rock is a name applied by Clough to crush-rock which has a very compact black matrix with subvitreous lustre—flinty in appearance, *not* in composition. Clough first met what he called "flinty-like streaks [which] occur along the lines of greatest crushing" in the Cheviot Hills (1888, p. 23) ; and later he found many examples in the North-West Highlands (1907, index, 18 refs.—commoner still in the Outer Hebrides). Meanwhile T. Holland independently investigated instances, called trap-shotten bands, in southern India (1900, pp. 198, 248) ; while S. J. Shand's pseudotachylyte, later described from the Orange Free State (1917), would certainly be called flinty crush-rock if it occurred in Scotland. In the Glen Coe region flinty crush-rock is only found along or near to the Boundary-Fault. It is a product of partial melting, and much of the heat which it records is attributed to friction connected with *rapid* displacement.

Fault-Intrusion means in this memoir an intrusion contemporaneous with some phase of the Boundary-Fault of the Glen Coe Cauldron. On this understanding the terms *Main* and *Early Fault-Intrusions* are self-explanatory.

Great Glen Fault.—A *wrench-* or *tear-fault* is a fault along which the relative displacement of the two sides has been horizontal. Along a *dextral wrench* the far side has moved relatively to the right, and along a *sinistral* wrench, the far side has moved relatively to the left. According to Kennedy the Great Glen Fault is an unusually powerful sinistral wrench with a relative displacement of 65 miles.

E. B. B.

CHAPTER IV

METAMORPHIC ROCKS

APPIN RECUMBENT SYNCLINE

INTRODUCTION

THE schists of the Lochaber district, north of Loch Leven, can easily be correlated with those of the Appin district, south of the same ; but the Great Glen Fault along Loch Linnhe defeats any attempt at correlation between the Lochaber-Appin assemblage and that of Ardgour to the north-west. It has been found convenient to start with the Lochaber-Appin country, and to divide its description between chapters iv to vii, based on structural considerations, with a short *resumé* in chapter viii ; and then to pass on to Ardgour in chapter ix. Even so, the material of chapters iv to vii has had to be subdivided under eleven local headings A-K as set out in the Table of Contents.

A. ONICH TO FORT WILLIAM

Introduction.—Before proceeding to detail let us give a brief introduction, easy to follow on Sheet 53 (Geol.). The map shows that between Onich and Ben Nevis the following five stratigraphical groups are disposed in a north-east-striking fold which we have already spoken of in chapter iii as the Appin Fold :

Appin Phyllites (2, [1]*youngest*)
Appin Limestones (3)
Appin Quartzite (4)
Ballachulish Slates (5)
Ballachulish Limestone (6, *oldest*)

In the terminology explained in chapter iii, the listed formations are said to constitute the core of the Appin Fold, while older rocks either side constitute the envelope of this core. As regards age relations, we have already pointed out in chapter ii that the Appin Quartzite is shown by its current-bedding to be younger than the Ballachulish Slates. In other words the Appin Phyllites are, in this district, the youngest formation in the Appin Core. Also the formations of the core are younger than the formations of the envelope, so that the fold is in this sense synclinal.

In addition we have seen in chapter iii that the cross-section of the Appin Fold in Glen Nevis is synformal (Fig. 3, p. 39) and that this, combined with the mapping, indicates a south-west pitch from Glen Nevis to Onich. Further, the map brings out clearly that the regularity of the Appin Fold disappears in the envelope formations that lie beyond the outcrop of the Ballachulish Limestone. To the south-east the Ballachulish Limestone is followed by Leven Schists (7), whereas to the north-west it is succeeded, often immediately, by rocks referred to the Eilde Flag division (13, p. 40). This has led to the recognition of an important slide, the Fort William Slide, along the north-west boundary of the limestone (Figs. 2, 14, pp. 37, 94 and west end of Section AA, one-inch map).

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[1] The numbers attached to the various rock groups were introduced before it was known that the Appin Phyllites are the youngest of the list.

We shall now follow up this outline sketch with a little detail in two parts. The first concerns stratigraphy, and the second the Fort William Slide. We reserve for chapters vi-viii our reasons for interpreting the Appin Fold as a large-scale recumbent fold. Since the fold is a syncline the Fort William Slide, cutting out much of its lower limb, is a lag as defined in chapter iii.

Stratigraphical Detail.—The Appin Phyllites and Appin Limestones (2 and 3) may be taken together, since, on the Onich shore where both groups are well exposed, the limestone is in two parts—one at the margin of the Appin Quartzite (4), the other separated from this margin by a minor part of the phyllite development.

The *Appin Phyllite Group* (2) consists of grey pelitic sediments, with which, in many outcrops, flaggy fine-grained quartzite is abundantly intercalated. On the Onich shore quartzite beds seem to be restricted to the part lying between the two bands of Appin Limestone already mentioned. The younger portion of the phyllitic outcrop consists of homogeneous massive grey mica-slates and is well exposed on the foreshore in a small promontory east of Onich Pier.

East of this, the foreshore for half a mile shows alternating outcrops of limestone and phyllite, presumably with much repetition by isoclinal folding, the details of which have not been worked out (Fig. 2). The most easterly part of the combined outcrop of Appin Phyllites and Limestones, traversed from west to east and ending with the Appin Quartzite, presents the following outcrop widths:

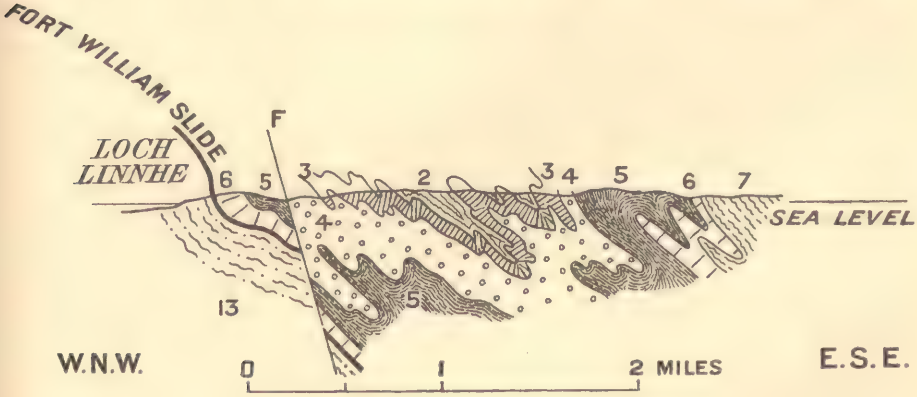

FIG. 2. Section across Appin Fold : Onich shore

2, Appin Phyllites (youngest) ; 3, Appin Limestone ; 4, Appin Quartzite ; 5, Ballachulish Slates ; 6, Ballachulish Limestone ; 7, Leven Schists ; 13, Eilde Flags

	Outcrop width	
	ft	in
Cream-coloured Appin Limestone, often with dark stripes, and interrupted by three thin lamprophyres (West)	153	0
Very pale blue-white limestone	4	6
Lamprophyre	19	0
Shear zone	—	—
Grey phyllite, with subordinate quartzose layers and one thin lamprophyre	70	0
Pinkish quartzite, essentially fine-grained	17	0

	Outcrop ft	width in
Mainly fine-grained quartzite with grey phyllitic beds and occasional thin gritty beds. Two very small porphyry pebbles have been found, the first by Clough (S 12909)[1]	10	0
White, grey and pink quartzite, mainly fine-grained	9	6
Pink quartzite, with a few thin grey phyllitic partings ; some beds gritty	11	6
Pink quartzite, often with distinct grains of blue quartz	15	0
Grey phyllite	0	6
Pink quartzite, with two phyllitic partings	11	6
Porphyritic dyke	9	0
Massive pinkish quartzite	10	6
Well-bedded cream-coloured Appin Limestone, some dark seams	19	0
Crush-zone, mainly flaggy grey phyllite	8	0
Edge of massive Appin Quartzite (East and oldest)	—	—

The two *Appin Limestone* (3) outcrops listed above are interpreted as separated stratigraphically by the phyllite-quartzite assemblage that intervenes in the shore exposure. What is called limestone in accounts of the Appin Limestone is generally magnesian, and is sometimes pure dolomite. Its beds often weather a pale cream or pink colour, and may be striped with impure dark seams (Tiger Rock). Most of it is somewhat sandy.

While details have not been established, the general pattern of outcrops is admirably shown in J. S. Grant Wilson's mapping in Sheet 53. For a rapid appreciation of the main structural features, a geologist is recommended to traverse the Appin Phyllite—Appin Limestone exposures of the coastal belt from east to west through Onich, and then, a mile to the north, go up the Amhainn Righ from west to east. Here he will see Appin Quartzite emerging with observable south-westerly pitch.

The *Appin Quartzite* (4) consists of two portions, each about 500 ft thick. The half near the Appin Limestone is a massive, white, false-bedded, gritty quartzite, with big detrital grains of quartz and felspar. It is admirably exposed along the road and coast a mile east of Onich. The other half is a striped transition group, consisting of alternating beds of quartzite and seams of black slate, linking up naturally with the Ballachulish Slates. It makes a stretch of overgrown raised-beach cliff east of the good road exposures just mentioned ; but it can be better studied inland round the northern extremity of the group outcrop.

The road-cutting across the massive part of the Appin Quartzite shows several instances of current-bedding, and in every case the quartzite youngs westwards towards the Appin Limestone and away from the striped transition group. Better still, on the shore, extreme low tide lays bare a continuous polished cross-section which reveals with surprising clarity that, throughout its whole thickness, the massive half of the Appin Quartzite youngs westwards. There is, it is true, a smash at the junction of Appin Quartzite and Appin Limestone ; but this is probably due to a trivial fault, and all evidence elsewhere agrees in showing the Appin Limestone to be the younger of the two formations.

The *Ballachulish Slates* (5) are well exhibited in a large quarry by the roadside a mile east of Onich. The group consists of black roofing slates with big undeformed cubes of pyrites. In this particular quarry, owing to proximity of the Ballachulish Quartz-Diorite across the water, the pyrites has been altered to aggregates of pyrrhotite (Neumann 1950), which weather to give holes. The slates are well exposed again on the shore west of Onich ; and inland they build large grassy hills stretching north to Glen Nevis. Their outcrop is easily followed and surrounds on three sides that of the Appin Quartzite, except where for a short space cut out by a fault east of Corran Narrows. Near the Ben Nevis Pluton the slates become hard and brittle and are spotted with cordierite ; but they remain black. They are in this condition where seen perched on top of the Ballachulish Limestone in the south wall of Glen Nevis (Fig. 3).

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[1] S followed by a number refers to a Scottish slice in the Geological Survey collection, London.

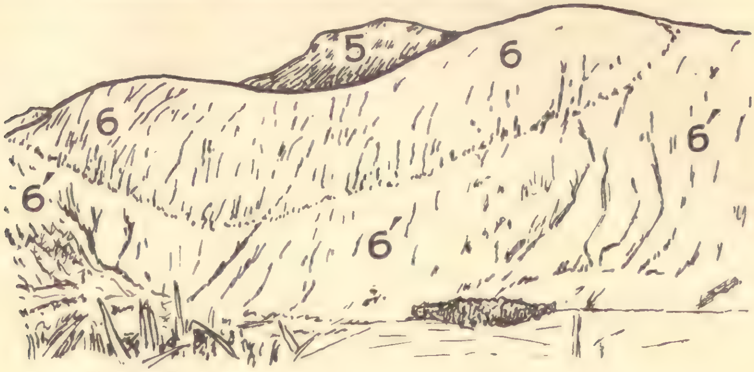


FIG. 3. Sketch of Appin Fold sectioned in S.W. wall of Glen Nevis

5, Baked Ballachulish Slates (youngest) ; 6, Marble of Ballachulish Limestone ; 6′, Calc-silicate-hornfels of Ballachulish Limestone

The *Ballachulish Limestone* (6) succeeds the Ballachulish Slates in a very clear shore section in the promontory west of Onich. The portion associated with these slates is a dark grey, sandy, fairly pure, banded limestone. The western part of the outcrop is very much more impure, and some is of a cream colour. The limestone is also well exposed east of Onich, where it forms conspicuous little crags at the hill-top above North Ballachulish. These are easily recognised from the road, but unfortunately the outcrop near the road itself is covered by glacial drift and raised beach. At the hilltop the part of the limestone group adjacent to the Ballachulish Slates is again dark, banded and fairly pure. East of this comes much more impure pale grey limestone with a prominent cream-coloured band near the junction with the next succeeding group, the Leven Schists (7).

It is easy to follow the eastern and western outcrops of Ballachulish Limestone until they unite around the Ballachulish Slates on the southern slopes of Glen Nevis (Fig. 3). Before this happens, however, at about a mile from the margin of the Ben Nevis Pluton, the more impure portion of the Ballachulish Limestone assumes the character of a flaggy, greenish white calc-silicate-hornfels—totally unlike the original limestone or calcareous schist in appearance. All that reaches the bottom of the glen is in this condition, and appears immensely thick owing, presumably, to steep isoclinal packing (S 15439-15443). On the hill slope to the south, in a broad rocky belt picked out in Fig. 3 below the cap of Ballachulish Slates, the purer portion of the limestone group has altered to dark marble with long prisms of tremolite. We have already commented in chapter iii upon the clear evidence which this natural cross-section affords of the synformal character of the Appin Fold in its outcrop between Glen Nevis and Onich.

We now pass from the core to the envelope of the Appin Fold. The original stratigraphical succession from Ballachulish Limestone (6) to Leven Schists (7) is only found on the south-east side of the Onich—Glen Nevis outcrop of this fold.

A strong argument that this is the original succession is afforded by its reappearance in typical form, in the Ballachulish Fold. Moreover, junction sections provide evidence of intercalation. For instance the crags above Glen Nevis show an interlaminated passage zone between Ballachulish Limestone (here calc-silicate-hornfels) and Leven Schists.

The *Leven Schists* (7) are excellently exposed in ice-moulded crags at the mouth of Loch Leven, north-east of Ballachulish Ferry. In the main they here consist of a great mass, probably two thousand feet or more thick, of greenish-grey phyllite or mica-schist, which apart from incessant colour lamination is wonderfully homogeneous. Quartzitic beds are confined to a comparatively thin, banded, transition zone, bordering outcrops of the Glen Coe Quartzite (8). This banded zone, treated as part of the Leven Schist formation, is composed of grey phyllite or mica-schist with occasional dark carbonaceous seams, together with quartzose ribs of various degrees of purity, some slightly calcareous.

The regional metamorphism of the Leven Schists increases in a general way from west to east. Near Loch Leven the western part of the outcrop is of phyllitic aspect with numerous small porphyroblasts of magnetite. The western part, on the other hand, is of definitely mica-schist type, spangled with biotite porphyroblasts, which are more abundant than the magnetites of the lower grade.

North-eastwards the whole outcrop (except for small patches seen beneath the downthrown lavas of Ben Nevis) develops the biotite porphyroblast facies, and with increasing metamorphism garnet becomes fairly common. Near the Mullach nan Coirean and Ben Nevis Plutons intense contact-alteration has been superinduced rendering the rocks harder and darker, often with conspicuous spotting due to development of cordierite.

The *Glen Coe Quartzite* (8) which follows this banded zone is a thick, fine-grained, well-bedded quartzite. As developed in Tom Meadhoin it is non-felspathic and free of mica.

The Glen Coe Quartzite of Tom Meadhoin and of a more continuous outcrop reaching north-east from Mam na Gualainn will be treated in Section H dealing with Kinlochleven (Fig. 14, p. 94 ; Fig. 15, p. 99). Suffice it here that it is separated stratigraphically from the Eilde Flags (13) of Loch-Eilde Mòr by Binnein Schists (9), Binnein Quartzite (10), Eilde Schists (11) and Eilde Quartzite (12) ; and that current-bedding shows that these formations are successively older in the order stated. This, of course, confirms the conclusion that the Appin Quartzite is older than the Appin Limestone.

The rocks claimed as *Eilde Flags* (13) from Corran Narrows to Glen Nevis upstream from Fort William are quartzo-felspathic flagstones rich in biotite and muscovite. Characteristic flags are seen in interrupted river exposures upstream from a quarry at the old Bridge of Nevis, Fort William, or more fully in Cow Hill close at hand. Near Corran Ferry thoroughly typical flags have disappeared, and the Ballachulish Limestone is bordered for a quarter of a mile, measured across strike, by flags more pelitic than is usual in the type Loch-Eilde Mòr area. These seem to belong to a division of the Eilde Flags, which, at Fort William, outcrops 1¼ miles away from the Ballachulish Limestone. At Corran they are followed by fine-grained *Linnhe Quartzite and Dark Schist* (p. 32), a horizon which has been exposed at numerous localities along the coastal road, departing from the outcrop of the Ballachulish Limestone at an angle of 15° measured in the horizontal plane. The stratigraphical significance of the Linnhe Quartzite and Dark Schist must be left to future workers. Before reaching Fort William the Linnhe Quartzite seems to fail ; but hard dark schist is exposed intimately associated with flags. For about a mile south-west of the outskirts of Fort William the coastal exposures are hopelessly broken by the Great Glen Fault.

Fort William Slide.—To turn now to the question of the correlation of the Fort William flags with the Eilde Flags. Since mapping leaves no doubt that all the rocks of the district, from Appin Phyllites to Ballachulish Limestone, are disposed in a fold (*cf.* Section AA at foot of Sheet 53 ; and Figs. 2, 3 in memoir), it is natural to look for the equivalents of the Fort William flags somewhere in the succession exposed south-east of the south-east outcrop of Ballachulish Limestone (Fig. 14) ; and the first formation with the requisite lithology is the Eilde Flags.

The break in the stratigraphical succession at the north-west margin of the Ballachulish Limestone outcrop can only be explained by postulating the great fold-fault, or slide, which is called the *Fort William Slide*. The north-west outcrop of Ballachulish Limestone keeps wonderfully parallel with this slide, for it is always represented except at about 1½ miles north of Corran Narrows. On the other hand, as has been pointed out, the Eilde Flags seem less parallel, allowing of a very appreciable south-westward approach of the Linnhe Quartzite and Dark Schist.

The Fort William Slide runs out to sea in the promontory west of Onich. A thin porphyrite or lamprophyre has here intruded along it, separating Ballachulish Limestone from intensely sheared, non-typical Eilde Flags.

In the river Kiachnish, six miles further north-east, the slide is repeated by a normal fault. The succession, seen twice, is Ballachulish Limestone, mica-schist (very thin), quartzite (very thin), Eilde Flags. It would be unsafe to correlate the mica-schist and quartzite, beyond recognising them as remnants of the formations completely cut out by the slide further south-west. The quartzite is more flaggy than is common in these formations where exposed south-east of the Appin Core, and minute examination reveals occasional instances of very gradual transgression of one divisional plane across another ; but, though the whole of the attenuated quartzite, from banded edge against mica-schist to contact with the Eilde Flags, is laid bare in the river, there is no more evidence of disruption than one is accustomed to find in ordinary exposures of schistose rocks. Mere inspection of the Fort William and other slides of the district as a whole often fails to suggest the importance attaching to these structures.

B. KENTALLEN TO APPIN

Introduction.—Kentallen Bay lies south of the entrance to Loch Leven. Appin House faces Shuna Island across the Sound of Shuna. Appin railway station is at Portnacroish, a mile to the south. The district may be considered as the south-westerly continuation of that described above.

As the one-inch map shows, there is considerable resemblance between the stratigraphy and structure exhibited in the Appin Fold, here and on the Onich Shore. At the same time the south-westerly pitch revealed between Glen Nevis and Onich brings in at least one additional formation, the black Cuil Bay Slates of Fig. 4. These slates are lithologically like the Ballachulish Slates, but are linked with the Appin Phyllites by an intercalatory passage zone. Further south-west, in Shuna Island, there is probably still another and younger formation, the Lismore Limestone, which repeats the characters of the dark purer portion of the Ballachulish Limestone. In the first edition of this memoir the black slates and dark grey limestone of Shuna were correlated with the Ballachulish Slates and Limestone, and their contact with the Cuil Bay Slates was interpreted as a slide. Since then the Creag Islands further south-west have been examined by the writer (Bailey 1925, p. 19), who now correlates the Shuna slates with the Cuil Bay Slates, and regards the Shuna, or Lismore, Limestone as younger still. On this understanding, the formations of the district, beginning with the youngest, are : Lismore Limestone (0), Cuil Bay Slates (1), Appin Phyllites (2), Appin Limestone (3), Appin Quartzite (4), Ballachulish Slate (5), Ballachulish Limestone (6), all included in the core of the Appin Fold ; and Leven Schists (7), to the south-east, belonging to the envelope (Figs. 4, 5). The core-formations (2-6) do not vary much in character from their representatives at Onich. The Leven Schists (7), however, develop a special facies.

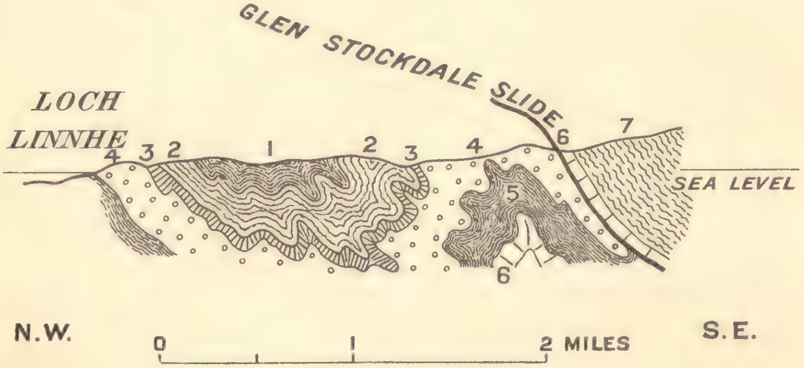


FIG. 4. Section across Appin Fold north of Cuil Bay

1, Cuil Bay Slates (youngest) ; 2, Appin Phyllites ; 3, Appin Limestone ; 4, Appin Quartzite ; 5, Ballachulish Slates ; 6, Ballachulish Limestone ; 7, Leven Schists

The tectonics of the district are more complicated than further north-east, and it is convenient to name two minor synforms and one minor antiform within the major Appin Synform. The more north-westerly of the former is the Cuil Bay Synform reaching from Kentallen south-west through Cuil Bay and Shuna. The more south-easterly is the broken Glen Stockdale Synform, the regularity of which is destroyed by the Glen Stockdale Slide of Figs. 4, 5. The two synforms are separated by the Beinn Sgluich Antiform, responsible for the main Appin Quartzite outcrop of the district. In this we often see an exposed core of the striped transition zone or even of the Ballachulish Slates. The Glen Stockdale Slide, as seen on the map, commonly brings Appin Phyllites and Limestone against Ballachulish Slates and Limestone.

Detail.—The *Lismore Limestone* (0) is restricted in Sheet 53 to Shuna and some rocks to the south-west. It is dark grey and fairly pure.

The *Cuil Bay Slates* (1) are black or dark grey, and are connected with the Appin Phyllites by interbanding. They occur only in the Cuil Bay Synform, and are seen at Cuil Bay and at Lurignich, 3 miles to the south-west, and again in Shuna.

The *Appin Phyllites* (2) outcrop in both the Cuil Bay and Glen Stockdale Synforms. They are somewhat more sandy than at Onich, so that much of the formation consists of grey quartzose mica-schist. Near Cuil Bay towards the

Appin Limestone, flaggy quartzite intercalations are common ; but only one band of Appin Limestone has here been identified, and it lies at the margin of the Appin Quartzite.

Near Kentallen the Appin Phyllites have been converted by the Ballachulish Quartz-Diorite into massive spotted cordierite-hornfels for a quarter of a mile from the contact.

The Appin Phyllites of the south-eastern limb of the Cuil Bay Synform extend south-west to opposite Shuna as a coastal, or near-coastal strip.

In the broken Glen Stockdale Synform there are three isolated outcrops of Appin Phyllites. The most northerly is crossed by Glen Duror, and shows interbanded quartzite and pelitic sediment baked by the Ballachulish Pluton. The middle outcrop lies south of Salachan Glen, where a quartzitic development separates two stratigraphically distinct bands of Appin Limestone. The most southerly is seen midway between Appin House and Glenstockdale farm.

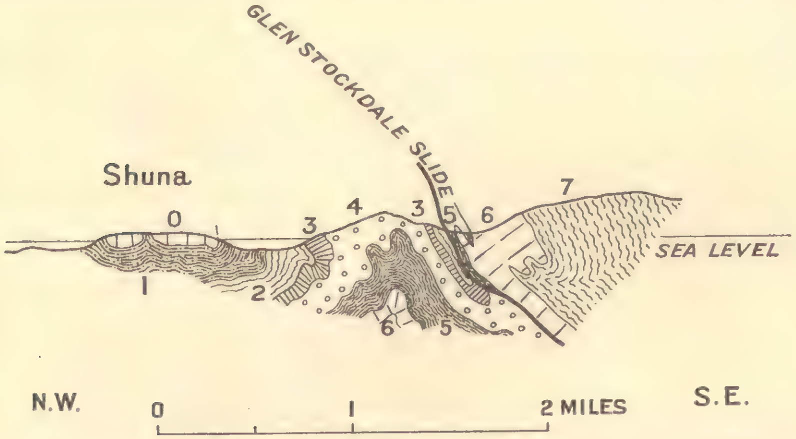


FIG. 5. Section across Appin Fold in Island of Shuna and Glen Stockdale

0, Lismore Limestone (youngest) ; 1, Cuil Bay Slates ; 2, Appin Phyllites ; 3, Appin Limestone ; 4, Appin Quartzite ; 5, Ballachulish Slates ; 6, Ballachulish Limestone ; 7, Leven Schists

The *Appin Limestone* (3) shows the same characters as at Onich, and is always magnesian. In fact it is being worked for dolomite near Dalnatrat south of Cuil Bay, where a thickness of 40 ft is seen, white, saccharoidal and with very little impurity. The dolomite is employed as an ingredient in the manufacture of rock-wool (chap. xxiii).

In the north-west limb of the Cuil Bay Synform the Appin Limestone is well exposed near Ardsheal Cottage, partly on the shore and partly in the cliff of the raised beach. On the shore it is of the striped, Tiger Rock type. In the south-east limb, exposures are excellent between the mouth of Glen Duror and Appin railway station at Portnacroish. At the latter place Appin Limestone may be seen passing through a transitional gritty calcareous bed into Appin Quartzite alongside.

Appin Limestone is well developed again in the Glen Stockdale Synform, and for a while south of Salachan Glen is in two distinct bands : the one separated from the Appin Quartzite is of the striped variety ; the other adjacent to the Appin Quartzite is massive and white.

The *Appin Quarztite* (4) is exactly as at Onich, massive and gritty in the half next the Appin Limestone, and striped with black slate in the half next the Ballachulish Slates. In the north-west limb of the Cuil Bay Synform, some of the massive half seems to be missing near Ardsheal Cottage. In the main outcrop, however, brought up by the Beinn Sgluich Antiform, the succession is complete.

Black *Ballachulish Slates* (5), exposed at intervals along the centre of the Beinn Sgluich Antiform, may be conveniently studied together with the striped transition zone of the Appin Quartzite near the road leading east from Appin railway station. In the Glen Stockdale Synform the slates occur as a long strip associated with Ballachulish Limestone. This strip is a virtual continuation of the Ballachulish Slate outcrop quarried by the roadside, a mile east of Onich. Here, however, it is always bounded to the north-west by the Glen Stockdale Slide which brings it as a rule into contact with Appin Limestone or Phyllite. It is interesting to note that the Glen Stockdale Slide is complementary in character to the Fort William Slide. It is a thrust, whereas it will be remembered the Fort William Slide is a lag.

The *Ballachulish Limestone* (6) is well exposed for seven miles along the south-east limb of the Glen Stockdale Synform. In this position it continues the more south-easterly outcrop of Ballachulish Limestone mapped north-east of Onich. It has the same stratigraphical features, dark grey and relatively pure towards the Ballachulish Slates, and pale grey and impure with white or cream-coloured fairly pure bands towards the Leven Schists. This is well shown in tributary burns of the valley south of Glenstockdale House.

The *Leven Schists* (7) of the envelope of the Appin Fold occupy a broad strip of country between Glen Stockdale and Glen Creran. For half a mile from the Glen Stockdale outcrop of Ballachulish Limestone the group is represented by pale greenish-grey phyllites of the type predominant in northern exposures, though less highly metamorphosed. Beyond this, thin dark seams begin to put in an appearance, just as they do further north in the relatively narrow banded passage zone bordering the Glen Coe Quartzite. In fact, the next three miles measured across strike, right up to the Ballachulish Slide reintroducing Ballachulish Limestone, consist in the main of an exaggeration of this banded zone with an enormous development of quartzose intercalations and black pelitic seams, finely interlaminated.

The pre-eminence of this banded assemblage gives the Leven Schists of the Appin district a distinctly peculiar facies. The change naturally does not come in abruptly : the road and railway cuttings along the shores of Loch Leven, north-east of the Ballachulish Pluton, already show an unusual number of black seams as compared with the north ; while, south of the pluton, black seams and quartzitic bands are fairly prominent and gather strength progressively.

A third of a mile within the north-western limit of the banded development, narrow outcrops of quartzite are met with intermittently along a line of strike passing east of Salachan. In the north-east the quartzite is massive, white and fine-grained. In the south-west, on the borders of the one-inch map, it is equally massive and white, but markedly gritty ; and it is linked by transition types with what appear to be banded Leven Schists. The stratigraphical and structural relations of these small quartzite exposures are as yet uncertain. E. B. B.

CHAPTER V

METAMORPHIC ROCKS
AONACH BEAG RECUMBENT SYNCLINE

C. Aonach Beag and Stob Bàn

Introduction.—Aonach Beag stands a couple of miles east of the summit of Ben Nevis, and reaching to 4060 ft is the highest schist mountain in Britain. The Aonach Beag belt now to be described is easily recognised on one-inch Sheet 53 (Geol.) owing to its associated outcrops of Ballachulish Limestone and Leven Schists. It extends south-westwards from the edge of the map through Aonach Beag and Meall Cumhann to the northern extremity of the Stob Bàn ridge overlooking Polldubh in Glen Nevis.

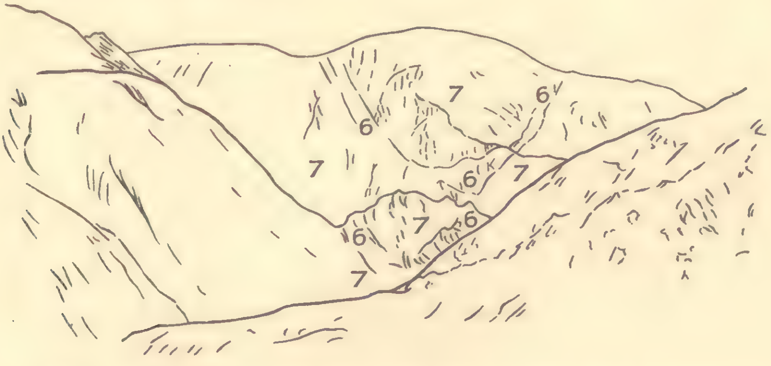


FIG. 6. View up Glen Nevis from Stob Bàn of Aonach Beag Synform

The Aonach Beag Core of Ballachulish Limestone (6), with Leven Schists (7) above and below, is refolded into a synform well seen in Aonach Beag (4060 ft) and also in Meall Cumhann in the middle distance

The Ballachulish Limestone serves as the core of a recumbent fold with Leven Schists providing the envelope both below and above. Since Ballachulish Limestone is younger than Leven Schists the Aonach Beag Recumbent Fold is a syncline. It has been bent into a very obvious secondary synform as can be seen in Aonach Beag and Meall Cumhann (Fig. 6) and again in the Stob Bàn ridge. As the limestone core has been cut through transversely by Allt Coire Giubhsachan between Aonach Beag and Meall Cumhann, and removed altogether by the Water of Nevis for two miles south-west of the latter, the order of structural superposition has been rendered diagrammatic.

Detail.—Before discussing stratigraphical correlations, we may point out that the *Ballachulish Limestone* (6) in this district is generally in the condition of a flaggy greenish-white calc-silicate-hornfels (S 13836, 13923). As such it is exactly like that part of the Ballachulish Limestone of the Appin Fold, which crosses the bottom of Glen Nevis between two and three miles south-east of Fort William. North-eastwards, however, at the map margin in some sections east of Allt Coire an Eòin it escapes from the aureole of the Ben Nevis Pluton and is pale grey or cream-coloured, and very sandy and impure, thus reproducing the characters normally found in unbaked Ballachulish Limestone associated with Leven Schists.

The underlying *Leven Schists* (7) are part of the type outcrop of Leven Schists, and, baked or unbaked, are of normal character. What are taken to be Leven Schists above the limestone in the secondary synform are immensely thick and indistinguishable in character from the Leven Schists below the same.

Discussion.—Let us now discuss the correlation of the Aonach Beag calc-silicate-hornfels with the impure portion of the Ballachulish Limestone :

(1) It is of the right character and is linked by transition beds with the Leven Schists.

(2) It is very thick and is therefore not likely to be a strictly local intercalation in the Leven Schists.

(3) Its position in the secondary synform is such that it does not structurally intervene between the Ballachulish Limestone and the Glen Coe Quartzite ; in other words, a traverse along the bottom of Glen Nevis from the Ballachulish Limestone (calc-silicate) of the Appin Fold east of Glen Nevis House to the Glen Coe Quartzite at Steall lies wholly on Leven Schists—the traverse passes under, not across, the Aonach Beag calc-silicate, synformally folded in Meall Cumhann (Fig. 6).

(4) No locality elsewhere furnishes a suggestion of a limestone structurally intervening between the Ballachulish Limestone and the Glen Coe Quartzite.

(5) The type of folding required by the correlation of the Aonach Beag calc-silicate with the Ballachulish Limestone is independently exemplified close at hand in Stob Bàn where Ballachulish Limestone *together with Ballachulish Slates* occupies the core of the Ballachulish Recumbent Fold, refolded (p. 47).

Secondary Synform.—Accepting, as seems necessary, the interpretation that the Aonach Beag calc-silicate is a recumbent fold-core, one is struck by the extent of the secondary steep-sided synform into which it has been bent. This synform is no less than 2000 ft deep. It is obvious that once a fold-core has been buckled in such fashion, its development as a fold-core must have come to an end.

The secondary folding at Aonach Beag has been accompanied by the production of a very pronounced vertical strain-slip cleavage, which affects a belt of country about a mile wide, including the Glen Nevis gorge. The strain-slip cleavage cuts and displaces quartz-veins, which presumably developed in connection with the recumbent episode (p. 24). E. B. B.

CHAPTER VI

METAMORPHIC ROCKS
BALLACHULISH RECUMBENT SYNCLINE

D. STOB BÀN TO CALLERT

Introduction at Stob Bàn.—The district that now falls to be described lies between Allt Coire a' Mhusgain, which drains from Stob Bàn into Glen Nevis near Polldubh, in the north, and Callert House on Loch Leven, in the south. Most of it, but not Stob Bàn, is included in Fig. 8. It is specially important as its interpretation provides a key to the tectonics of a large tract of country on the south, as well as on the north, of Loch Leven (*cf.* Fig. 7, E-H; Fig. 14, C,D; and Sheet 53). Other key localities might be cited, but this is the simplest.

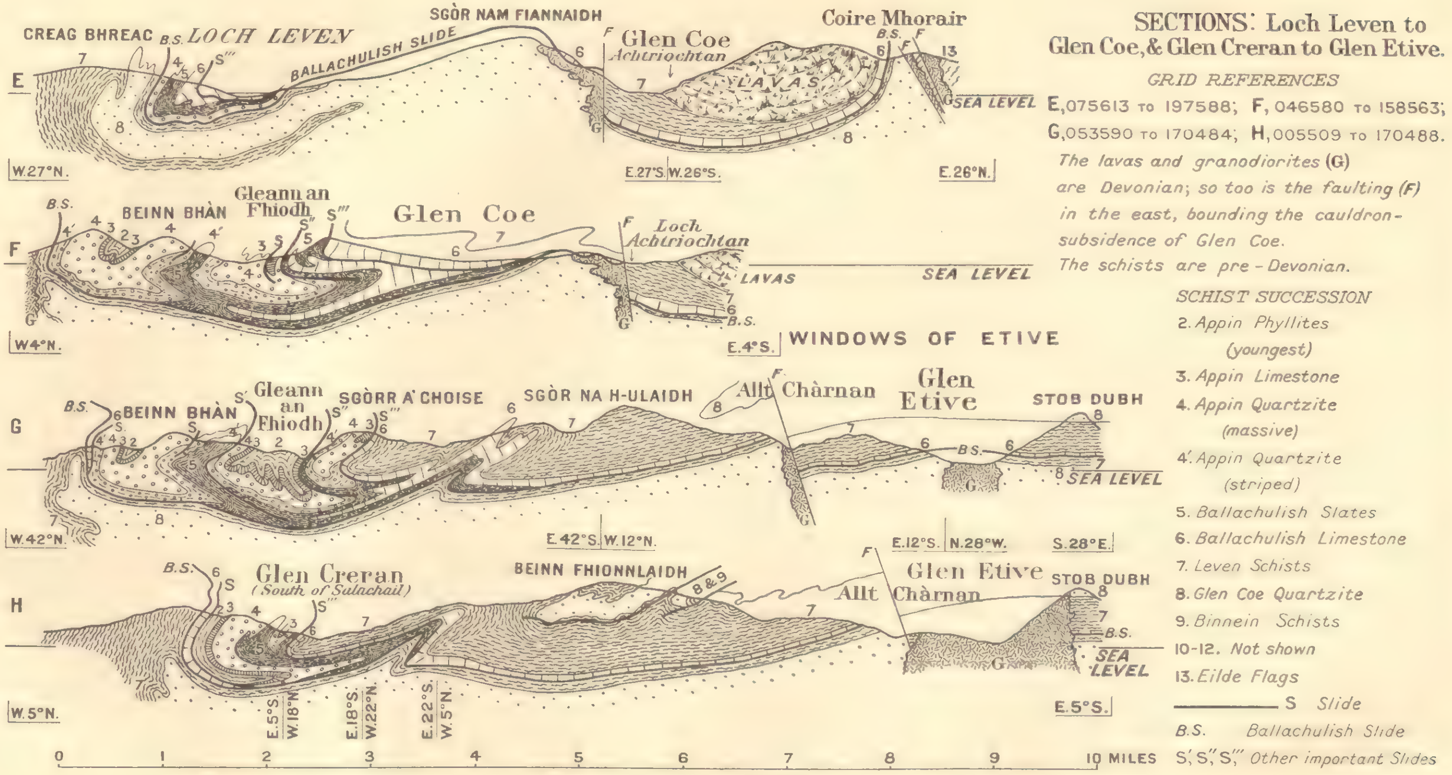
As shown on Sheet 53, the Aonach Beag recumbent synclinal fold-core, refolded into a secondary synform at the north end of the Stob Bàn ridge (chap. v), is followed a quarter of a mile to the south-east on the same ridge by another recumbent synclinal fold-core, refolded into another equally obvious secondary synform. This other synclinal fold-core (still half a mile north-west of the summit of Stob Bàn) consists of both Ballachulish Limestone and Ballachulish Slates. It is therefore fuller in a stratigraphical sense than the Aonach Beag recumbent fold-core lying to the north-west. Accordingly we treat the two fold-cores as closely related, rather than identical, since, as will be more fully understood presently, the recumbent synclines of the district gape towards the north-west and as a rule take in more and more stratigraphical groups in that direction. We therefore give the fuller recumbent syncline, involved in the more south-easterly secondary synform, a name of its own—it is the great *Ballachulish Recumbent Syncline*; and we treat the Aonach Beag Recumbent Syncline as a digitation at a slightly lower level (Fig. 17, p. 112). The distinction between these two recumbent synclines does not, however, involve any important matter of principle, which is fortunate since the criterion employed to separate them is not altogether trustworthy. This difficulty will be apparent when we come to describe Glen Creran (p. 65), where the Ballachulish Core is, very locally, fuller towards the close than towards the gape—a result, presumably, of complicated sliding.

As explained in chapter iii, the same convention is used in the stratigraphical definition of the Ballachulish Core as has been employed in regard to the Appin and Aonach Beag Cores: the Ballachulish Limestone (6) and younger formations are classed as core-rocks; while the Leven Schists (7) and older formations are treated as envelope-rocks.

The section of the Ballachulish Fold as exposed on the steep face of the Stob Bàn ridge overlooking Allt Coire a' Mhusgain reads as follows:

(7) Cover of thick Leven Schists (hornfelsed) in the heart of the secondary synform
(6) Upper layer of Ballachulish Limestone (calc-silicate-hornfels), 100 ft
CORE (5) Black Ballachulish Slates (hornfelsed), 100 ft
(6) Lower layer of Ballachulish Limestone (calc-silicate-hornfels), 100 ft
(7) Basement of thick Leven Schists (hornfelsed) in contact at both sides with Glen Coe Quartzite (8)

Both the cover and the basement Leven Schists belong to the envelope.



SECTIONS: Loch Leven to Glen Coe, & Glen Creran to Glen Etive.

GRID REFERENCES

E, 075613 to 197588; F, 046580 to 158563;
G, 053590 to 170484; H, 005509 to 170488.

The lavas and granodiorites (G) are Devonian; so too is the faulting (F) in the east, bounding the cauldron-subsidence of Glen Coe. The schists are pre-Devonian.

SCHIST SUCCESSION

2. *Appin Phyllites (youngest)*
3. *Appin Limestone*
4. *Appin Quartzite (massive)*
4'. *Appin Quartzite (striped)*
5. *Ballachulish Slates*
6. *Ballachulish Limestone*
7. *Leven Schists*
8. *Glen Coe Quartzite*
9. *Binnein Schists*
10-12. *Not shown*
13. *Eilde Flags*

——— S *Slide*
B.S. *Ballachulish Slide*
S', S'', S''' *Other important Slides*

FIG. 7. Sections: Loch Leven to Glen Coe, and Glen Creran to Glen Etive

The correlations involved in our table admit of no doubt. The Ballachulish Slates (5), for instance, can be picked up south-west of the Mullach nan Coirean Granite in the Lairigmòr valley of Fig. 8, and can be followed thence to the Ballachulish slate quarries at Ballachulish village (Laroch) south of Loch Leven.

For any young geologist who enjoys a scramble the Stob Bàn section of the refolded Ballachulish Fold is the most rewarding of any in the one-inch map. Let us imagine that such a one has satisfied himself of the reality of the secondary synform, and has then climbed back to the summit of the ridge to consider the consequences. The map (Sheet 53) shows him at once that this little secondary synform necessitates a secondary synformal interpretation affecting the Ballachulish Fold in all the district to the south as far as the Cruachan " Granite ".

To begin with, its continuation can be recognised with certainty in the Lairigmòr valley of Fig. 8. Beyond this it is joined by two other secondary synforms pitching south-west off the slopes of Mam na Gualainn. Next, crossing Loch Leven, it expands mightily, as shown by the increasing separation of the two outcrops of what we have called the basement Leven Schists of the Stob Bàn exposure. One of these outcrops crosses the loch east of Ballachulish Ferry and then, after interruption by the Ballachulish Pluton, continues south-westwards through Fraochaidh and Beinn Mhic na Céisich. The other crosses the loch east of Callert, at the same time turning at right angles to the south-east where it can be followed along the lower reaches of Glen Coe. In the great basin-shaped depression within the angle separating these divergent outcrops, the Ballachulish Core, consisting of Ballachulish Limestone and younger formations, is covered by a broad spread of overlying Leven Schists. These latter correspond with the cover of Leven Schists occupying the heart of the secondary synform at Stob Bàn ; but south of Loch Leven pitch extends their outcrop eastwards to reach from Sgòrr a' Choise and Salachail to the lavas of the Cauldron-Subsidence of Glen Coe. At three localities in this broad spread, Beinn Fhionnlaidh, Beinn Maol Chaluim and Stob Dubh (Section B of one-inch map and Sections G, H, Fig. 7 of p. 48) the Leven Schists carry conspicuous caps of Glen Coe Quartzite, belonging in a broad sense to the upper limb of the Ballachulish Fold. Coupled with this, in Gleann Chàrnan, Gleann Fhaolain and Glen Etive, the so-called Windows, they are cut through by erosion to give glimpses of underlying Ballachulish Limestone resting on basement Leven Schists, which in turn rest on Glen Coe Quartzite belonging to the lower limb of the Ballachulish Fold.

In the windows just mentioned, Ballachulish Limestone alone separates basement from cover Leven Schists, which is one less formation than at Stob Bàn ; but in the district reaching three miles west of the mouth of Glen Coe the core of the Ballachulish Fold, separating basement from cover Leven Schists, includes Ballachulish Limestone, Ballachulish Slates, Appin Quartzite, Appin Limestone and Appin Phyllites, the same great assemblage as we have described in the Appin Fold-Core at Onich.

South of Mullach nan Coirean Granite.—It is time now to leave Stob Bàn, and, crossing the Mullach nan Coirean Granite, to examine outcrops on the north-east face of the Lairigmòr valley of Fig. 8. The secondary synform of Stob Bàn here includes baked Ballachulish Slates as its central formation, without any of the cover of Ballachulish Limestone and Leven Schists present on Stob Bàn. In fact, the cover Leven Schists of the envelope are not to be seen again north of Loch Leven.

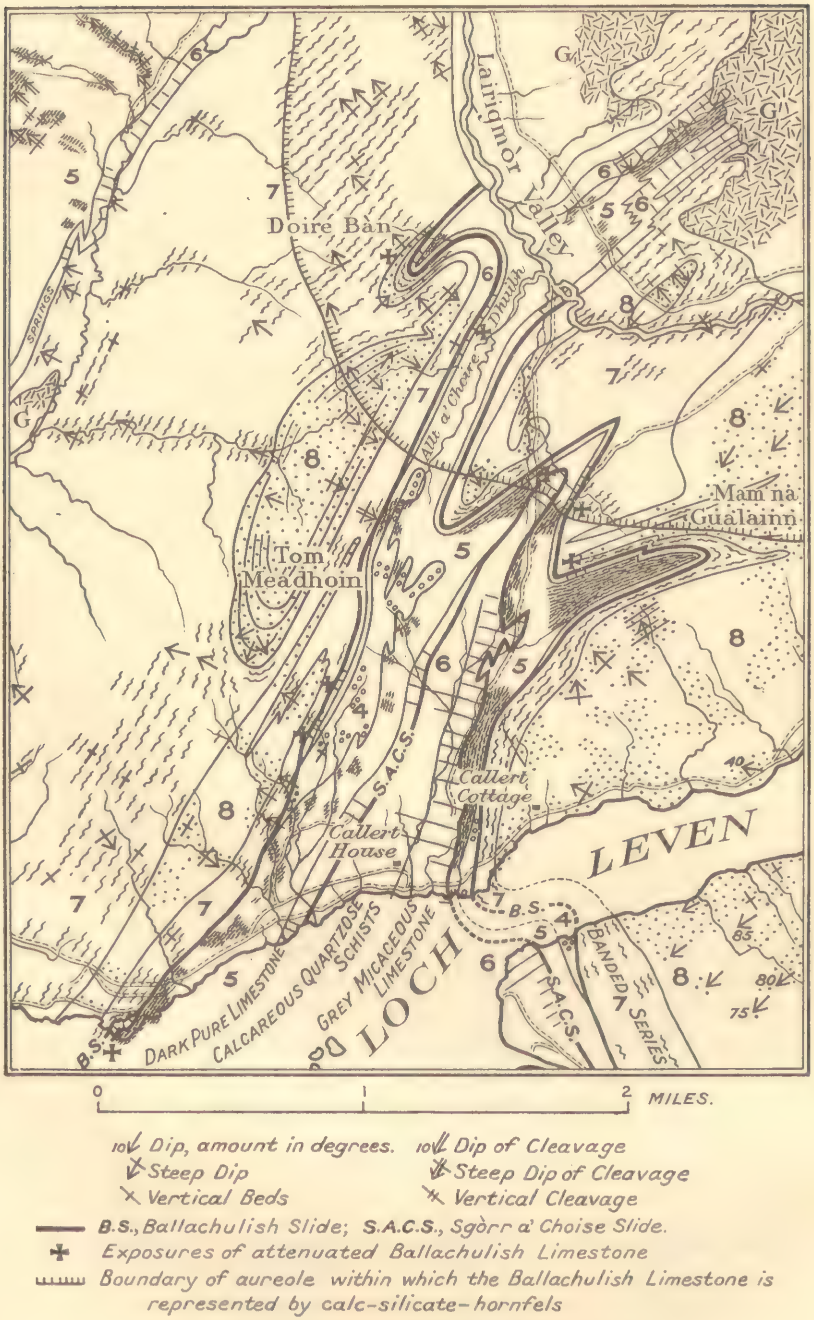


FIG. 8. Map showing outcrops in Callert district

4, Appin Quartzite (youngest) ; 5, Ballachulish Slates ; 6, Ballachulish Limestone ; 7, Leven Schists ; 8, Glen Coe Quartzite ; G, Granite

The Ballachulish Slates are thicker than at Stob Bàn, and on either side the underlying layer of Ballachulish Limestone (calc-silicate-hornfels) is strongly developed on the hill-top near the granite margin. The basement Leven Schists beyond are also thick. Exposures are intermittent, but on crossing the Lairigmòr valley (Fig. 8) one realises a great change in the development of the Ballachulish Fold : the lower limb shows marked attenuation, leading in many cases to total disappearance of one or more recognisable horizons.

Ballachulish Slide.—This attenuation is connected with the most interesting slide in the whole district, to wit the Ballachulish Slide. On the one-inch map and in Fig. 8 this slide is shown by a heavy line starting south of the Lairigmòr valley. No doubt the slide continues north-east to the Stob Bàn ridge, cutting out, for instance, all the dark pure portion of the Ballachulish Limestone expected next the Ballachulish Slates : but its effects in this direction are much less conspicuous than they are south of the Lairigmòr valley.

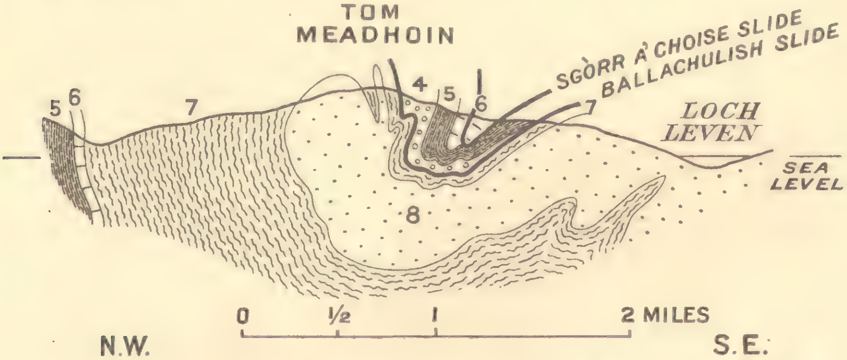


FIG. 9. Section across Fig. 8 showing the relation of the Ballachulish Slide to the Tom Meadhoin Antiform

4, Appin Quartzite (youngest) ; 5, Ballachulish Slates ; 6, Ballachulish Limestone ; 7, Leven Schists ; 8, Glen Coe Quartzite

A brief examination demonstrates that the Ballachulish Slide must have developed before the Ballachulish Fold was bent into the secondary Stob Bàn Synform. It is found, in fact, that the eastern and western outcrops of the lower limb of the Ballachulish Fold show precisely similar phenomena of attenuation (Figs. 8,9). In keeping with this, in the hollow west of Mam na Gualainn, where the Stob Bàn Synform is joined by two others of like type, the attenuated lower limb with the Ballachulish Slide has a corresponding zig-zag outcrop.

Three great formations are affected by attenuation in connection with the Ballachulish Slide in this district, namely the Ballachulish Slates (5), Ballachulish Limestone (6) and Leven Schists (7). The next four paragraphs are written for those who propose to use Fig. 8 as a guide to their thoughts rather than their feet. The remainder of our account of the Callert district will then be devoted to those who can give a day to its exposures and thus attain conviction in the field.

Naturally one can appreciate the attenuation of the Ballachulish Slates (5) in the lower limb of the Ballachulish Fold only where Appin Quartzite is present in the heart of the Appin Fold—elsewhere one cannot distinguish the slates in the lower limb from those in the upper. The requisite condition is fulfilled for a mile and a half on the north-western side of the Stob Bàn secondary synform, where

Appin Quartzite has been mapped as a strip east of Tom Meadhoin ; and also for a short space on the eastern side of the expanded Stob Bàn Synform, in the Loch Leven shore section east of Callert House. On the north-western side, the Ballachulish Slates (5) and Ballachulish Limestone (6), which might be expected to intervene between the Appin Quartzite (4) and the Leven Schists (7), are in some exposures reduced to a few feet in thickness, and in others cut out altogether. In like manner on the east side of the synform, at Loch Leven, both formations are entirely missing.

Marked reduction is sometimes easier to realise than complete elimination, for the presence of a remnant reassures us that we are searching the right place. Eight localities are marked in Fig. 8 with a heavy little cross to indicate exposures of a few feet of Ballachulish Limestone (often calc-silicate-hornfels, Fig. 39, p. 237) in the anticipated position. The contrast between attenuation in the lower limb and thick development in the upper limb of the recumbent Ballachulish Fold is most striking. A damaged, but representative outcrop of Ballachulish Limestone in the upper limb has been preserved from erosion in the central part of the secondary synform, and stretches from Callert House for about a mile and a half inland. The borders of this outcrop consist of limestone, pure or micaceous. The central tract, seen in streams north-east of Callert House, is made up of slightly calcareous silvery-grey quartzose schists—correlatable with the impure part of the stratigraphical group covered by the name Ballachulish Limestone, as defined elsewhere.

Passing now to the envelope, we find particularly instructive phenomena of attenuation furnished by the basement or foundation Leven Schists (7). On the north-west of the expanded Stob Bàn secondary synform, west of Mam na Gualainn, lies a thoroughly well exposed antiform of Glen Coe Quartzite (8) forming Tom Meadhoin (Fig. 8). On its south-east side the quartzite is separated from outcrops of Ballachulish Limestone and Slates (6 and 5) and Appin Quartzite (4) by a narrow belt of Leven Schists in one extreme case reduced to 30 ft in thickness ; and yet the Leven Schists, when followed round the nose of the Tom Meadhoin Antiform, are found to make an uninterrupted band a mile wide, in spite of marked dissection into hills and valleys. The Leven Schists (along with the Glen Coe Quartzite) belong to the combined envelope of the Ballachulish and Appin Cores : the thinned-out development serves as basement to the Ballachulish Core ; the thick development, as cover to the Appin Core. Clearly a slide, the Ballachulish Slide, accounts for the thinning that is so obvious close to the south-east margin of the quartzite in the Tom Meadhoin Antiform. In passing we may note that current-bedding in the Glen Coe Quartzite at Tom Meadhoin shows that Glen Coe Quartzite is older than Leven Schists.

Two facts of first class importance emerge from examining the Tom Meadhoin exposures. The first is that the Tom Meadhoin Antiform, unlike the Stob Bàn Synform, is contemporaneous with the formation of the Ballachulish Fold and Slide. The second is that, as the Tom Meadhoin Antiform closes towards the north-west (Fig. 9), the complementary Ballachulish Fold must close towards the south-east. This conclusion is supported by the much greater prominence of Appin Quartzite on the western than on the eastern side of the secondary Stob Bàn Synform as expanded in the Callert district (Figs. 8, 9). Across the loch in the Ballachulish (Laroch) district the south-eastward close of the Ballachulish Fold may be said to be self-evident, since the core at Ballachulish is much fuller than at Glen Coe (*cf.* Pl. III and Fig. 10).

Callert Excursion.—The following is an itinerary suitable for an individual or party seeking confirmation of the main structural features of the Callert district (Figs. 8, 9). We assume a start from the Onich-Kinlochleven coastal road.

A convenient beginning is made with the Ballachulish Slide on the shore of Loch Leven opposite Eilean Choinneich, 1½ miles west of Callert House. The slide outcrops about 200 yd S.E. of a band of Glen Coe Quartzite (8), quarried at the roadside. In this space the shore shows intermittent exposures of Leven Schists (7) consisting of grey phyllites with some black seams, quartzite ribs and slightly calcareous beds. The whole is a typical representative of the banded portion of the Leven Schists expected near the Glen Coe Quartzite. Close to the eastern limit of the phyllitic exposures there is an outcrop of black slate, 12 ft wide, beyond which, to the east, we find the following : grey phyllite, 36 ft ; gap, 45 ft ; grey limestone, banded to east with black slate, 6 ft ; striped quartzite and black slate, soon followed by good black slates.

In considering this coast section we may neglect the 12 ft of black slate interposed among the grey phyllites. Its interpretation is ambiguous : it may either be an exaggeration of the black seams commonly found in the banded edge of the Leven Schists near Glen Coe Quartzite, or it may be a tectonic slice of Ballachulish Slates. In either case it is an irrelevant detail.

Leaving this point unsettled, we have what seems *to all local appearance* to be a straightforward stratigraphical succession starting from banded Leven Schists (7) and ending up with Ballachulish Slates (5). There is no repetition of outcrop to suggest a fold ; but looking across the loch, with Sheet 53 or Pl. III to help us, we see that the striped quartzite and black slate of our shore belongs to the transition half of the Appin Quartzite (4), and that this, three quarters of a mile to the south, behind St. John's Church, opens up synformally to enclose in its gape the massive half of the Appin Quartzite followed by Appin Limestone (3) and Appin Phyllites (2). We can now interpret our northern shore section opposite Eilean Choinneich with confidence as follows from west to east :

> *Lower Limb of Ballachulish Fold* (West) : Banded Schists (7) ; *slide* omitting most of the Leven Schists and most of the Ballachulish Limestone ; remnant of Ballachulish Limestone (6) ; *slide* omitting Ballachulish Slate (5).
>
> *Heart of Ballachulish Fold* : Striped zone of Appin Quartzite (4).
>
> *Upper Limb of Ballachulish Fold* (East) : Ballachulish Slate (5).

The banded Leven Schists (7) of the lower limb of the Ballachulish Fold correspond with what we have called basement Leven Schists at Stob Bàn, and form part of the envelope of the Ballachulish Core—to which latter all the younger formations (6,5,4) are to be assigned. The two slides enumerated are branches of the *Ballachulish Slide*. The Ballachulish Slates (5) of the eastern, upper limb of the Ballachulish Fold as seen in this shore section belong manifestly to the northern continuation of the quarried type-outcrop across the loch. They are well exposed again close at hand near the road and in burns west of Callert House.

Ballachulish Limestone (6), which, like the slates just mentioned, must belong in the upper limb of the Ballachulish Fold, is seen further east at two places on the shore indicated by notes on Fig. 8. In the more westerly of these, the limestone is dark and pure, such as normally comes against Ballachulish Slates (more particularly in the relatively simple country of the Appin Fold). In the more easterly, though still grey, it is highly micaceous and impure. It must, therefore, be separated from the black phyllites (Ballachulish Slates) immediately to the east (see below) by a slide. In the greater part of the Ballachulish, Creran and Glen Coe districts (Pls. III, IV and Fig. 10), a corresponding slide has been found, and it has been named the *Sgòrr a' Choise Slide* (S.A.C.S. of Fig. 14 ; S''' of Fig. 7) from a mountain two miles south of Loch Leven (Pl. III).

The Sgòrr a' Choise Slide differs from the Ballachulish Slide in that it thins the upper, instead of the lower, limb of the Ballachulish Recumbent Syncline. It is therefore a thrust rather than a lag. It has, however, been affected very clearly, for instance at Loch Creran (Pl. IV), by the secondary synformal folding that we have discussed on the Stob Bàn ridge. In agreement with this we find a double outcrop at Callert. The more westerly separates the calcareous quartzose schists, noted on Fig. 8, from the pure grey limestone on the north-west. It is almost certain that the stratigraphical position of these calcareous quartzose schists (seen in a little stream north-east of Callert House) is between the grey micaceous limestone on the south-east and the Leven Schists.

East of the grey micaceous limestone on the coast, that is immediately across the Sgòrr a' Choise Slide, we find from west to east :

		Outcrop width in feet
UPPER LIMB OF BALLACHULISH FOLD	Black graphitic phyllites, mostly covered by beach (Ballachulish Slates, 5, much reduced by movement)	120
	Intensely sheared rusty graphitic phyllites with quartzite and quartzose bands—pyrites common (striped transition zone of Appin Quartzite, 4, much reduced by movement)	40
	Intensely sheared white quartzite, with gritty texture very seldom preserved (massive part of Appin Quartzite, 4, marking the centre of the Ballachulish Fold—the foundations of a summerhouse serve as a landmark)	100
LOWER LIMB OF BALLACHULISH FOLD	Intensely sheared rusty interbedded quartzite, quartzose bands and graphitic phyllite—pyrites common (striped transition zone of the Appin Quartzite, 4, much reduced by movement, but retaining more of the quartzitic portion than is found in the western outcrop)	40
	Ballachulish Slide (very well exposed and marking the base of the Ballachulish Core)	—
	Grey non-rusty, very thin-bedded, massive mica-schists, with biotite porphyroblasts (typical Leven Schists, 7, belonging to the basement position in the Ballachulish Envelope)	45

The Ballachulish Slide indicated above cuts out the greater part of the striped zone of the Appin Quartzite, the whole of the Ballachulish Slates and Limestone, and the greater part of the Leven Schists, since what remains of these latter is only about 300 ft thick before Glen Coe Quartzite is reached. A very moderate estimate places the total omitted, at 2500 ft. The precise position of the slide on the shore is easy to find, as it is marked by a strong contrast in lithology. Moreover the sea waves, while developing little ridges and hollows along the greatly disturbed bedding of the striped Appin zone, have left the adjacent Leven Schists with smooth joint faces.

It will be noted that attenuation and special shearing has affected the upper limb of the Ballachulish Fold east of Callert House, though it has not reduced it nearly so much as the lower limb. If time permit, a visitor should satisfy himself beyond doubt that the thin black graphitic phyllites, classed as Ballachulish Slates of the upper limb in our table, are stratigraphically Ballachulish Slates. All that is necessary is to follow the crumpled black phyllite inland along what is virtually a continuous exposure (Fig. 8) till at three quarters of a mile from the coast it is seen in much less disturbed condition, and unmistakably of Ballachulish Slate type. Half a mile further north the black slate outcrop thus reached is separated from Leven Schists by a thin representative of the Ballachulish Limestone indicated by three heavy crosses west of Mam na Gualainn on Fig. 8.

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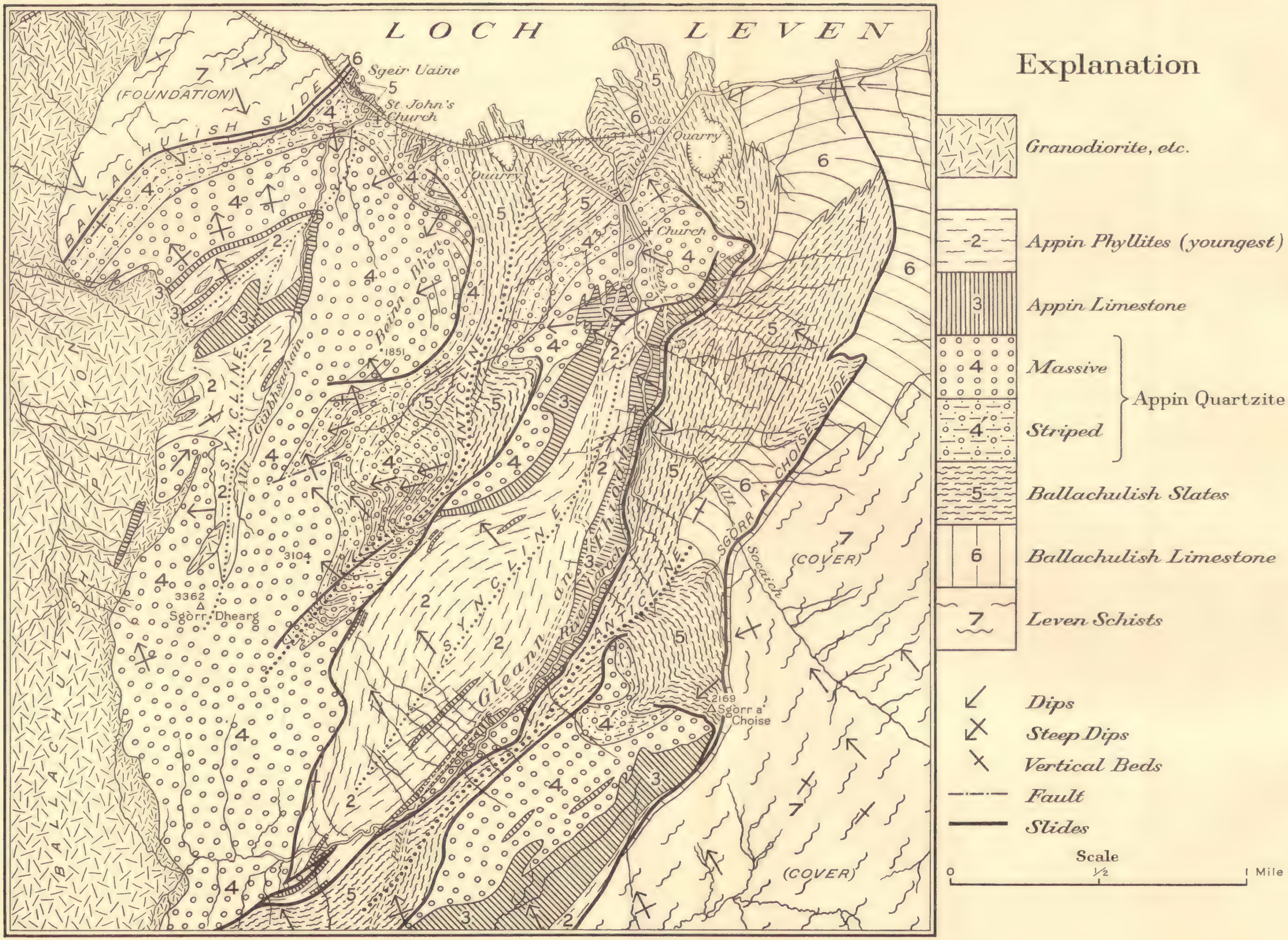


MAP OF BALLACHULISH DISTRICT

Having got so far a visitor should certainly go west to the well-exposed antiform of Tom Meadhoin, showing re-emergence of envelope in the basement position. With the help of the map and section (Figs. 8,9) and the description already given, a geologist should have no difficulty in realising the great tectonic contrast between the south-east and north-west sides of this antiform.

Before reaching Tom Meadhoin, special shearing is obvious along the Ballachulish Slide in a small gorge at the head of Allt a' Choire Dhuibh. Here a section is afforded from massive Appin Quartzite, through much-diminished representatives of the striped zone and Ballachulish Slates to what remains of the Leven Schists, with Ballachulish Limestone omitted. There is evident smashing, but whether contemporaneous with the slide or later is uncertain.

From Tom Meadhoin a traverse of a mile somewhat south of east takes us across Leven Schists undiminished by the Ballachulish Slide. Beyond, it is easy to find the crag, west of Leac Mhòr on the one-inch map, where Ballachulish Limestone of the south-east limb of the Appin Fold looks down upon North Ballachulish. We here reach the equivalent (along strike) of the north-western end of Fig. 9. Comparing this figure with Section A at the foot of the one-inch map, it is easy to realise that the Glen Coe Quartzite of Tom Meadhoin, the oldest rock of the district, belongs to the core of a great complex recumbent anticline, and that this anticline which is named after Kinlochleven in chapter vii separates the Ballachulish Recumbent Syncline above from that of Appin below. It is clear too that the Ballachulish and Fort William Slides are homologous, both of them lags developed in the lower unreversed limbs of recumbent synclines.

E. BALLACHULISH TO SGÒRR A' CHOISE

Introduction.—The Ballachulish district, mostly included in Pl. III, extends from near the ferry eastwards along Loch Leven to the mouth of Glen Coe (see Sheet 53). Its western boundary is marked by the Ballachulish Pluton ; and its southern extremity by a broad outcrop of hornfelsed Ballachulish Slates east of the southern tip of this intrusive complex. Access is easy, and evidence regarding the gape of the Ballachulish Fold is spectacular. Among other features is a roadside demonstration of the *Ballachulish Slide* at St. John's Church (Pl. III). It is noteworthy, however, that the district, taken in isolation, affords no evidence whatever of the essentially recumbent character of the Ballachulish Fold and Slide. Most of the rocks as exposed stand steeply and constitute a complex synform including within its limits a succession of subsidiary steep synforms and antiforms (Fig. 7, F, G).

The Ballachulish Slide (B.S., Fig. 7) at St. John's Church is seen on the west side of the Ballachulish Fold. It here goes underground, as shown west of Beinn Bhàn in Fig. 7, F, G, to reappear to the east outside of Pl. III in Glen Coe (Fig. 10) and the Windows of Etive. Visitors with limited time should concentrate on the St. John's exposure followed by examination of the type section of the reappearance 2¼ miles to the east-north-east at a boathouse on Lochlevenside due north of Glencoe House (p. 72). The connection between what is seen at these two localities is supplied by the invaluable evidence already considered in the Callert district (D, p. 47).

The complementary *Sgòrr a' Choise Slide* (S''' on Fig. 7) is best demonstrated by climbing Sgòrr a' Choise, which is highly to be recommended to those who are young and active.

The secondary synformal distribution of the Ballachulish Fold, with its attendant slides, as illustrated in Fig. 7, has already been realised by our hypothetical young geologist standing on the Stob Bàn ridge with his back to Glen Nevis (p. 49).

The stratigraphy of the Ballachulish district is the same as that described in the Appin district (chapter iv), extending from Appin Phyllites (2, youngest), through Appin Limestone (3), Appin Quartzite (4), Ballachulish Slates (5), Ballachulish Limestone (6) to Leven Schists (7). According to our convention the Ballachulish Limestone and younger formations are referred to the *core* of the Ballachulish Recumbent Fold, and the Leven Schists to the *envelope*.

The Leven Schists, just as on the Stob Bàn ridge, occupy two contrasted positions in respect of their associates : they function as a foundation or basement, outcropping west of the Ballachulish Slide in the north-west corner of Pl. III ; and also as a cover, spreading out east of Sgòrr a' Choise (Fig. 7, G).

The facies of the various formations is as at Onich (A), so that only a few local notes on stratigraphy are required.

Stratigraphical Detail.—The *Appin Phyllites* (2) are grey phyllites with, in many exposures, a very large proportion of flaggy fine-grained quartzite intercalations. There is a good display on the western slopes of Gleann an Fhiodh (Pl. III). In the valley west of Beinn Bhàn, owing to proximity of the Ballachulish Pluton, the phyllites are altered to massive spotted cordierite-hornfels, and, where banded with quartzite, resemble baked representatives of the striped zone of the Appin Quartzite.

The *Appin Limestone or Dolomite* (3) presents both types met with in the Onich and Appin district. The cream or pink, dark-banded type, Tiger Rock, has been unsuccessfully quarried as an ornamental stone in a " Marble Quarry " a little west of the River Laroch in Gleann an Fhiodh, 700 yards up from the bridge in Ballachulish village. Much purer white dolomite is seen close at hand against Appin Quartzite in the important tributary that drains the south slopes of Beinn Bhàn. Some of the purer variety weathers in gritty fashion through loosening of dolomite crystals following solution of calcite matrix. The massive pure variety is also exposed on the top of Sgòrr a' Choise, again close to Appin Quartzite ; it weathers with the faintest of blue-white tints.

In the Allt Giùbhsachain valley west of Beinn Bhàn, and again (beyond Pl. III) two miles south-west of Sgòrr a' Choise summit, the Appin Limestone is greatly altered by the Ballachulish Pluton. In the last-named exposure dedolomitisation has produced a grey limestone, studded with innumerable little crystals of forsterite, usually serpentinised.

The half of the *Appin Quartzite* (4) next to the Appin Limestone is massive gritty felspathic quartzite. The other half (4′ in Fig. 7), next the Ballachulish Slates, is the usual striped transition zone, showing endless intercalations of quartzite and black slate. The combined thickness is 1000 ft. The massive quartzite, as exposed in Allt Giùbhsachain above St. John's Church, intervenes between exposures of Appin Limestone on the south and the striped transition zone on the north ; and it shows repeated current-bedding, consistently younging towards the Appin Limestone.

The Ballachulish exposures of the striped transition zone are especially good. Interfolded isoclinally with the Ballachulish Slates they are seen for a quarter of a mile along the shore and road at St. John's Church ; and east of this they give an excellent uninterrupted exposure for 200 yards upstream from the Laroch bridge at the entrance to Gleann an Fhiodh. In Sgòrr Dhearg again they build the greater part of a cliff which makes a very conspicuous object as seen from Ballachulish village. A few calcareous layers are found in the heart of the striped zone ; and abundance of pyrites makes the whole group prone to rusty weathering—emphasised where the pyrites has been converted to pyrrhotite near the Ballachulish Pluton (p. 251).

The black *Ballachulish Slates* (5) are opened up in huge quarries by the roadside. They afford a few instances of graded bedding.

The *Ballachulish Limestone* (6) is a big and varied formation. A good exposure along the road immediately east of the slate quarries begins with dark grey, tolerably pure, sandy limestone, corresponding with the dark pure outcrop half a mile W.S.W. of Callert House across Loch Leven (Fig. 8). At Bridge of Coe, a mile to the east, what is seen in the river can still be called grey limestone, but it is paler and very impure and micaceous. It corresponds in turn with the grey micaceous limestone noted in Fig. 8 on the shore south-east of Callert House. In between these outcrops is a mass of slightly calcareous schist or phyllite, obviously an exaggerated continuation of the calcareous quartzose schists of Fig. 8. This mass of slightly calcareous schist makes the wooded slopes leading down from the rounded Leven Schist summit of Meall Mòr to the bottom of Glen Coe, where it affords several characteristic exposures along the new road of Fig. 10. One of these, opposite Leacantuim and the Youth Hostel, shows some white limestone, probably very close to Leven Schists.

Although in a sense the country from the slate quarries to Bridge of Coe is the type locality for the Ballachulish Limestone, it is so complicated tectonically that it is not nearly as satisfactory for this purpose as the hilltop exposure east of Onich. It suffers especially from the presence of the Sgòrr a' Choise Slide (Pl. III ; S‴ of Fig. 7). However, when all the available evidence is assembled, the Ballachulish district agrees with the Onich district in giving the Ballachulish Limestone : (*a*) a dark pure development against Ballachulish Slates ; (*b*) a great mass of calcareous schist as a middle member ; and (*c*) a white or cream-coloured limestone against Leven Schists. The Bridge of Coe exposure probably belongs to the passage from (*a*) to (*b*). Group (*a*), already noted just east of the Ballachulish slate quarries, reappears excellently exposed, a mile further south in Allt Socaich at the foot of Sgòrr a' Choise. It is here succeeded to the east by Group (*b*), much curtailed by the Sgòrr a' Choise Slide. Beyond the slide follows Group (*c*), and then the Leven Schists.

The *Leven Schists* (7) on the west side of the outcrop of the Ballachulish Fold, between Loch Leven and the Ballachulish Pluton, are grey phyllites or mica-schists with numerous small porphyroblasts of biotite, and sometimes garnet—altered to cordierite. They carry many interbedded thin black seams and, in the eastern part of the section, numerous bands of fine-grained quartzite too. These Leven Schists, we have already pointed out, are part of the basement or foundation, upon which the Ballachulish Limestone and later formations of the district lie in complicated folds.

The corresponding cover of Leven Schists, overlying the Ballachulish Limestone, etc., makes Meall Mòr and other mountains east of Sgòrr a' Choise. It was reached in the Allt Socaich section when we crossed the cream-coloured edge of the Ballachulish Limestone ; but its further consideration belongs to the Glen Coe and Glen Etive district (I).

Tectonic Detail.—We may now turn to tectonic relations. The gape of the Ballachulish Fold is highly complex, and includes within itself three minor synforms called after Beinn Bhàn, Gleann an Fhiodh, and Sgòrr a' Choise (Fig. 7). As these synforms have cores of relatively young formations, they can be called synclines, and this term is used in Pl. III.

The synformal nature of the Beinn Bhàn Fold is self-evident above St. John's Church. The dip of the Appin Quartzite is almost vertical in the north-west limb, whereas it is directed towards the north-west at much more moderate angles in the south-east limb. Moreover the pitch of the fold is clearly, though steeply, towards the south-west, in which direction additional formations are taken on. E. B. B.

The synformal nature of the Gleann an Fhiodh Fold is inferred because an observed antiform intervenes between it and the Beinn Bhàn Synform. This antiform, with cleavage developed parallel to its axial plane, is seen to good advantage in the striped transition zone of the Appin Quartzite laid bare in an easily accessible semi-cliff due east of the summit of Sgòrr Dhearg and south of the precipice which is so conspicuous from the village. It should be visited by anyone who wishes to check the structural interpretations given in Fig. 7, F, G. The regularity of the antiform, as exposed in the cliff, is broken somewhat by a slide marked by a conspicuous hollow with discordance of dip on its two sides. This slide is shown on the map, but is of trivial importance. A more important slide is indicated on the map a little to the south-east and lettered S′ in Fig. 7, G ; it does not, however, in any way impair the regular development of the antiform as exposed in the cliff.

E. B. B., H. B. M.

The synformal nature of the Sgòrr a' Choise Fold is merely inferred on analogy with that of the Beinn Bhàn and Gleann an Fhiodh Synforms.

The two main complementary slides (lag and thrust) of the district, generally spoken of as the Ballachulish and Sgòrr a' Choise Slides respectively, will be dealt with in the accounts that immediately follow of excursions to St. John's Church, Gleann an Fhiodh and Sgòrr a' Choise.

St. John's Church Excursion.—Before actually starting our excursion from Ballachulish village, let us mention two features of the Beinn Bhàn Synform, which most visitors will be prepared to accept without leaving the road (Pl. III). The mapping of the Appin Phyllites (2), Appin Limestone (3) and Appin Quartzite (4) of Beinn Bhàn and Allt Giùbhsachain shows that these rocks have a perfectly regular arrangement, except in the two following particulars :

(1) It has not been found possible to trace the outcrop of the Appin Limestone completely round that of the Appin Phyllites in the valley of Allt Giùbhsachain. Exposures are bad, but locally the limestone can be proved to be absent probably as a result of minor sliding.

(2) The junction of the massive quartzite and the striped zones of the Appin Quartzite on the east face of Beinn Bhàn is certainly a minor slide as shown in Pl. III and Fig. 7. There is a discordance of dip and strike on the two sides of this slide, so that its presence is easily recognised at a distance, for instance in the view from Ballachulish railway station.

Now we come to the excursion proper :

The regularity of the Beinn Bhàn Synform breaks down altogether near St. John's Church when we pass outwards from the striped zone of the Appin Quartzite. One need scarcely leave the roadside to realise this important feature. At the west end of Ballachulish (Laroch) village there are large quarries in Ballachulish Slates (5). These quarries are opened near the centre of the antiform separating the Beinn Bhàn and Gleann an Fhiodh Synforms. With neighbouring exposures they indicate beyond doubt that the Ballachulish Slates are represented in full force on the east side of the Beinn Bhàn Synform (Fig. 7, F, G). Two hundred yards west of the quarries the striped rocks of the Appin Quartzite put in a first roadside appearance. Thereafter for about half a mile Ballachulish Slates and striped Appin Quartzite alternate, all dipping steeply north-west. This must be due to zig-zag interfolding of slates and stripes, for on the hill face above the road the junction between striped and overlying massive Appin Quartzite follows a uniform line descending north-westwards until it reaches the axial plane of the synform, near Allt Giùbhsachain. It then sweeps up almost vertically ; but the Ballachulish Slates (5) which have gone out to sea *do not reappear*. Instead, on the shore and for three-quarters of a mile inland, the striped rocks are bounded on the north-west by a thin representative of the grey pure part of the Ballachulish Limestone (6), followed by the banded transition group that elsewhere links Leven Schists (7) with Glen Coe Quartzite (8).

Here is easily examined detail :

The best section to show the elimination of Ballachulish Slates is afforded in a little promontory west of St. John's Church. The most westerly outcrop of Ballachulish Slates here makes a small skerry called Sgeir Uaine on Pl. III. West of this for 50 yards the foreshore is occupied by part of the striped zone of the Appin Quartzite, including a thin bed of sandy limestone. Then follows typical, rather pure, grey Ballachulish Limestone, 12 yards across. Beyond this, immediately, come banded Leven Schists, undoubtedly marginal to Glen Coe Quartzite. The latter does not come to the surface here ; but, as we have seen already, it outcrops on the same line, north of the loch (Fig. 8).

The exposure is complicated by the presence of non-schistose lamprophyre dykes that flank the Ballachulish Limestone on either side ; but the more north-westerly of these allows the slide between Ballachulish Limestone and banded Levens to be examined for a foot along its outcrop. Both dykes are considerably shattered, which shows that some of the obvious disturbance affecting the striped Appin Quartzite may be much later than the Ballachulish Slide.

Let us summarise what we learn from this locality :

(1) The Ballachulish Slide is in two main branches either side of the Ballachulish Limestone : on the south-east side it cuts out all the Ballachulish Slates ; on the north-west it cuts out much the greater part of both the Ballachulish Limestone and the Leven Schists.

(2) The Beinn Bhàn Synform does not fold the Ballachulish Slide and must therefore be contemporaneous with it.

(3) The Beinn Bhàn, Gleann an Fhiodh and Sgòrr a'Choise Synforms are synclinal in the sense that they have cores of younger formations.

(4) Together they are incidents in the gape of the Ballachulish Fold in the manner indicated in Fig. 7.

(5) Coupled with what is seen in Glen Coe and Glen Etive (p. 83) they teach us that the Ballachulish Fold is a recumbent syncline closing towards the south-east.

(6) The Ballachulish Slide reducing the lower, normal limb of the Ballachulish recumbent syncline is therefore a lag, not a thrust.

E. B. B.

Gleann an Fhiodh and Sgòrr a' Choise Excursion.—For those who have the time the following excursion is recommended from Ballachulish village up Gleann an Fhiodh and Allt Socaich (1½ miles) ; then ascent and traverse of Sgòrr a' Choise (2 miles) ; and return by Gleann an Fhiodh (3 miles). Such an excursion, even if Sgòrr a' Choise is not climbed, will greatly help anyone furnished with the one-inch map and Pl. III to appreciate the minor folds of Gleann an Fhiodh and Sgòrr a' Choise as illustrated in Fig .7.

For completeness one may start with a visit to the grey, relatively pure portion of the Ballachulish Limestone (6) in the upper limb of the Ballachulish Fold, exposed by the roadside east of the village (an extra half mile). This is followed to the west by Ballachulish Slates (5) opened in an immense quarry. Still keeping to the road one next meets with the striped transition zone of the Appin Quartzite (4) in its natural position bordering the slates. This thick zone is more fully exposed in the River Laroch upstream from the bridge in Ballachulish village. Here it occupies the bed of the burn as far as the Established Church, when gritty Appin Quartzite puts in an appearance. Appin Limestone (3) is wanting in the river section at the eastern margin of this quartzite outcrop, for a slide of small importance brings the latter into direct contact with green-grey Appin Phyllites (2), interbanded with thin ribs of cream-coloured limestone—unfortunately the slide itself is not exposed. Part of the missing outcrop of Appin Limestone is well seen in a " Marble Quarry " on the west side of the river. It is here cream and pale pink in colour with dark stripes (Tiger Rock). The marginal portion, a much purer white dolomite, is exposed interfolded with Appin Quartzite in an important tributary stream just a little to the north of the quarry.

The phyllites, mentioned above as slid against Appin Quartzite in the main river, mark the centre of the Gleann an Fhiodh Syncline at this locality. Soon to the south a return outcrop of Appin Limestone appears, and furnishes the river bed for 400 yards. Then, above a waterfall, Appin Quartzite, at first massive and gritty, later striped and transitional, follows with marked attenuation. This attenuation, which is maintained along strike for three miles, is the evidence for the slide S″ of Sections F and G (Fig. 7).

The attenuated Appin Quartzite, well exposed in the river, shows the following signs of disruption :

(1) the face of quartzite over which the water tumbles at the fall is slickensided ;

(2) the quartzite a little farther upstream is in a crushed condition and is crossed by well-defined planes of movement ;

(3) the striped succession beyond the quartzite is, like the quartzite proper, of greatly diminished thickness and is crossed by planes of movement which cut the bedding structures at so small an angle that their presence is only revealed by careful scrutiny.

Beyond the striped zone of the Appin Quartzite there is, especially in Allt Socaich, a fine exposure of Ballachulish Slates (5), belonging to the same outcrop as carries the great quarry near the coast. Next in this tributary, just as at the quarry, comes dark-grey, pure, banded Ballachulish Limestone (6). This is followed by a succession of slates, both black and grey, with numerous bands of limestone, mostly dark, but some cream-coloured—a mixed assemblage referable to the preponderant, very impure, middle member of the Ballachulish Limestone series. Immediately to the east is cream-coloured limestone, several feet thick, still belonging to the Ballachulish Limestone and followed by a great uninterrupted outcrop of Leven Schists (7).

Let us recall that the Leven Schists west of St. John's Church on Lochlevenside belong to the foundation which, at Stob Bàn (p. 47), supports the Ballachulish Limestone and later formations assigned to the core of the Ballachulish Recumbent Syncline. Now our two Ballachulish excursions have taken us right across the outcrop of this complex core ; and we, at Allt Socaich at the foot of Sgòrr a' Choise, stand on Leven Schists, which function as its cover (Fig. 7, G). The further consideration of this cover will be reserved for descriptions of Glen Creran, Glen Coe and Glen Etive (District I, p. 83).

Here for completeness we must interpolate an explanation regarding the ground north of Allt Socaich, which we shall not have time to visit during this excursion. It will be seen that Pl. III shows the Sgòrr a' Choise Slide (S‴, Fig. 7) as continuing across the two miles which separate Allt Socaich from Loch Leven ;

whereas Sheet 53 shows the same slide as terminating a very short distance north of the stream. The difference of expression is due to a desire not to overload the one-inch map. It so happens that the Sgòrr a' Choise Slide shows in very dramatic fashion south of Allt Socaich (see sequel), and to omit it there would often render the one-inch map unintelligible. To the north its effects are more subdued. They exist, however. Thus the dark pure portion of the Ballachulish Limestone is confined to those portions of the formational outcrop which bulge westward at Allt Socaich and again at the coastal slate quarry. In between, Ballachulish Slates, for more than a mile along their east margin, make direct contact with impure calcareous schist or pale limestone. H. B. M., E. B. B.

In Allt Socaich, to resume our excursion, the main effect of the slide is greatly to curtail the outcrop of the mixed calcareous schist division which normally separates the grey and cream-coloured margins of the Ballachulish Limestone. In addition some black slate in this mixed division, immediately west of the cream-coloured marginal limestone, shows signs of special disturbance.

Climbing now out of Allt Socaich we follow the crop of the cream-coloured limestone to the top of Sgòrr a' Choise. At the summit a steep pitch introduces Appin Quartzite, striped and massive, and Appin Limestone, of the unbanded white type (presumably pure dolomite). The effect of the Sgòrr a' Choise Slide here becomes exceedingly obvious, for, whereas on the north-west side of the Sgòrr a' Choise Fold Ballachulish Slates and Appin Quartzite are developed in force, on the south-east side these two formations are reduced to 3 ft each in thickness ; and at the same time all of the Ballachulish Limestone Series as exposed in Allt Socaich is cut out except for the cream-coloured margin. Accordingly we find this latter, south-east of the slide, separated from white Appin Limestone, in the heart of the Sgòrr a' Choise Fold by a mere 6 ft of strata. The attenuation can be followed in its various stages of accomplishment along the line marked in Pl. III as a subsidiary slide running north of west 30 yd S. of the Sgòrr a' Choise cairn. Bands in the steeply pitching striped zone of the Appin Quartzite are broken into a series of lenticles.

If the traverse be continued south-westwards along the ridge of Sgòrr a' Choise so as to reach the path leading back into Gleann an Fhiodh, it will be found that the Appin Quartzite on its north-west side is bounded by yet another slide. This has resulted in a severely " scrubbed " face of quartzite on the hillside south-east of the point at which the path crosses the River Laroch. The quartzite here is in the condition of the Durness Quartzite of the North-West Highlands where crossed by one or other of the well-known thrusts of the region.

Half a mile upstream from where the path just mentioned crosses the River Laroch, exposures, partly in tributaries entering from the south, show the termination of the Appin Phyllite outcrop that further north, half a mile wide, marks the heart of the Gleann an Fhiodh Synform. The structures involved are highly complex, and the available evidence is insufficient to elucidate them in detail. The return journey by path down Gleann an Fhiodh is sufficiently illustrated in Pl. III.

F. GLEN CRERAN

Allt Eilidh South to Ellerie.—This sub-district starts a little south of Pl. III and reaches for a short distance into Pl. IV. Allt Eilidh is a tributary of Glen Creran draining the south-eastern slopes of the Sgòrr a' Choise ridge. Ellerie is a house a little north of the junction of Glen Creran and Glen Ure. Both are named on Sheet 53, and the latter also on Pl. IV. The geology continues south-westwards that of the Ballachulish district (E), as may be seen from examination of Sheet 53, and that part of Fig. 7, H, which crosses Glen Creran south of Salachail.

Ballachulish Limestone (6) and the younger formations, Ballachulish Slates (5), Appin Quartzite (4), Appin Limestone (3) and Appin Phyllites (2), mark the core of the Ballachulish Fold. To the north-west, from Fraochaidh to Beinn Mhic na Céisich, Leven Schists (7) of the envelope emerge as foundation to this core. To the south-east, from Meall an Aodainn to Leac Bharainn, they follow on as cover.

The Leven Schists of the foundation-outcrop, right up to their eastern contact with Ballachulish Limestone, are of the banded type characteristic on a large scale of the older part of the formation south-west of the Ballachulish Pluton (p. 44). The non-banded younger portion, seen further west in Meall Bàn, is cut out eastwards by the Ballachulish Slide, here generally double as at St. John's Church on Loch Leven. In contrast, the Leven Schists of the cover start with a great thickness of the unbanded younger portion, making unbroken contact with Ballachulish Limestone as in Allt Socaich (p. 60).

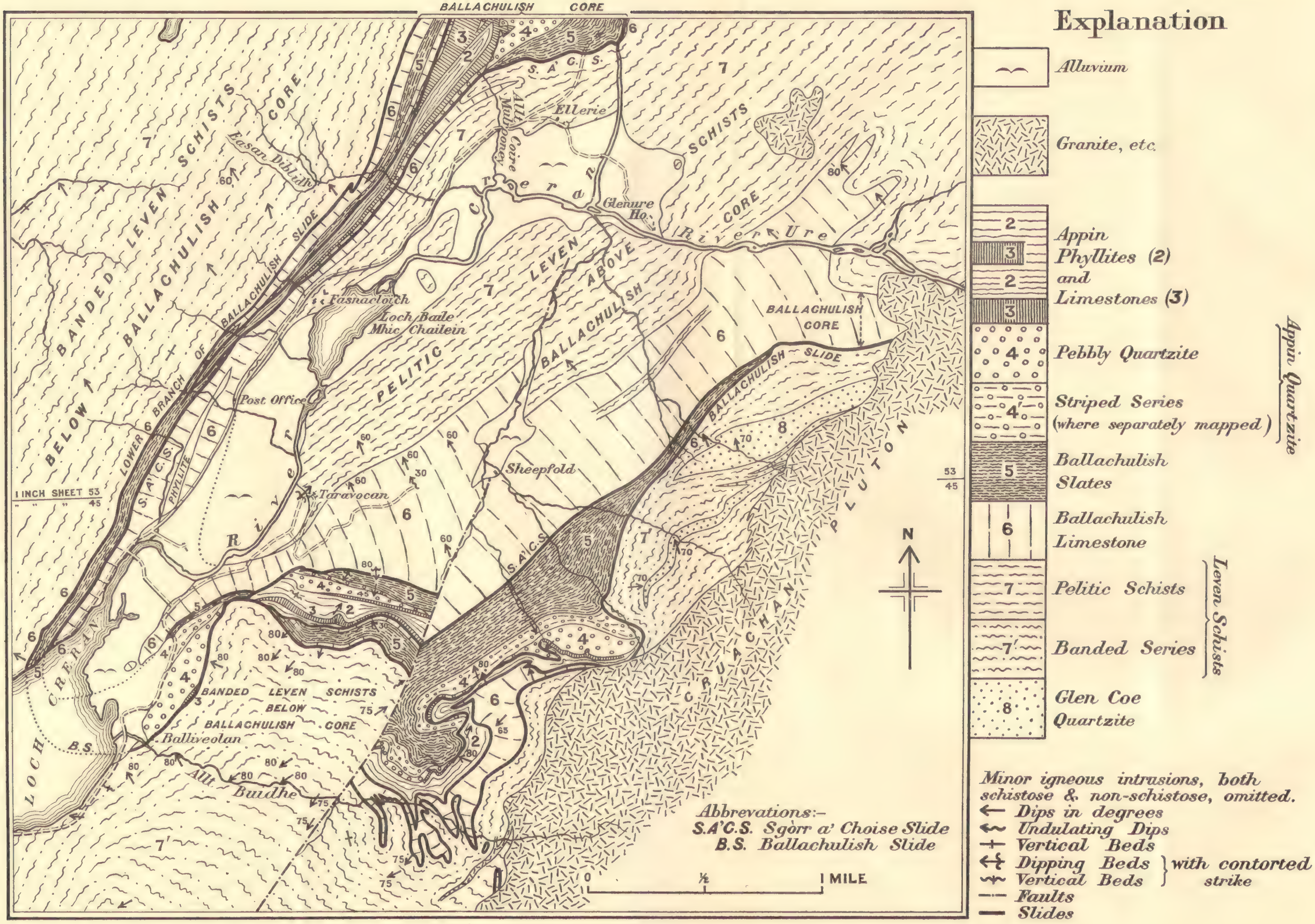
The dissimilarity between the two sides of the Ballachulish Fold is even more marked when we consider the representation of the Ballachulish Limestone. On the west side the only part of the Ballachulish Limestone to be recognised is the pure, dark-grey portion that is expected against Ballachulish Slates. On the east the only part is the cream-coloured edge, or corresponding calc-silicate-hornfels, expected against Leven Schists.

Here are a few details :

On the west, for the first quarter of a mile south of the Ballachulish Pluton, the Ballachulish Slide can be traced as dividing the banded Leven Schists of Fraochaidh, at first, from Ballachulish Slates and, further south, from Appin Phyllites. Where the Appin Phyllites occur, the slide is followed by thin discontinuous outcrops of very pale limestone, perhaps Appin Limestone. After quarter of a mile, however, the slide becomes manifestly double, with anything up to 300 yd separating its two branches. In between is dark, pure Ballachulish Limestone, often accompanied by important bands of Ballachulish Slates.

On the other side of the gape of the Ballachulish Fold we find the Sgòrr a' Choise Slide (S‴, Fig. 7, H) strikingly displayed. Let us start where the present district overlaps the Ballachulish District south of a small pluton, one and a half miles S.W. of Sgòrr a' Choise and half a mile S.W. of Pl. III. Sheet 53 indicates that the slide here greatly reduces the Ballachulish Slates (5) and Limestone (6) that intervene between Appin Quartzite (4) on the north-west and Leven Schists (7) on the south-east. Two tributaries of Allt Eilidh cross the Gleann an Fhiodh path, coming from Pl. III and now descending towards Salachail. In the more northerly stream the attenuated groups are represented by a very few feet of black slate and calc-silicate-hornfels. In the more southerly, conditions are probably the same, but there is a small gap in the exposures where the calc-silicate might be expected.

A mile to the south-west, in another burn, running down the hill slope to pass close to Salachail, the Sgòrr a' Choise Slide is laid bare at a small waterfall. Its effect here has been to bring an extensive outcrop of Ballachulish Slates on the north-west into contact with the cream-coloured edge of the Ballachulish Limestone (no longer hornfelsed) followed by Leven Schists on the south-east. The cream-coloured limestone is traversed by obliquely convergent planes of movement. The exposure is particularly clear. Its main features are repeated to the south-west in the River Creran, but they are confused by subsequent faulting.



MAP OF LOWER GLEN CRERAN

This takes us into Pl. IV. For the next half mile to Allt Coire Mulrooney west of Ellerie, the Sgòrr a' Choise Slide brings Ballachulish Slates into direct contact with Leven Schists. Meanwhile the Ballachulish Core, measured from the basement to the cover outcrop of the Leven Schist envelope, is narrowing. In Easan Diblidh, west of Ellerie, it is less than 300 yards wide. This contrasts strongly with the 3-mile measurement north-west of Sgòrr a' Choise in Pl. III. The contents of the core in Easan Diblidh dip steeply north-west and are from west to east as follows :

	Outcrop width in feet
Ballachulish Slide (*W. branch*)—at structural base	—
Ballachulish Limestone (pure part of 6) and Slates (5) : both black ..	400
Ballachulish Slide (*E. branch*)	—
Appin Phyllites (2) : grey with quartzitic and calcareous beds	150
Appin Limestone (3) : typical white	50
Appin Quartzite (4) : unstriped portion	50
Sgòrr a' Choise Slide	—
Ballachulish Limestone (6) : highly impure, pale portion—at structural top	300

It is safe to assume that the small outcrop widths of the individual formations are all due to mechanical thinning.

Looking back northwards, the one-inch map shows us how the gape of the Ballachulish Fold continuously widens towards and at the Ballachulish Pluton. It is already a mile wide, where it meets the great intrusion. The formations involved in this direction are the same as are listed above in Easan Diblidh ; only they are often developed on a much more ample scale.

Exposures are excellent in Allt Coire Mulrooney and its tributaries, north-east of Easan Diblidh. The only lithological feature that need be noted is that the Appin Phyllites in several places contain thin black seams suggesting a passage to the Cuil Bay Slates (1) that are represented in the Appin Core.

The various formations are disposed in three main folds which probably correspond with the Sgòrr a' Choise, Gleann an Fhiodh and Beinn Bhàn Synforms of the Ballachulish district. The structural connexion, however, is not quite certain, because, where the two districts meet east of the southern tip of the Ballachulish Pluton, no formation younger than the Ballachulish Slates has been spared by erosion ; and in the slate outcrop structural details cannot be traced.

If we confine attention to rocks younger than the Ballachulish Slates, we may provisionally assign outcrops in the Allt Coire Mulrooney drainage basin as follows from east to west :

The *Sgòrr a' Choise Synform* probably includes all the Appin Quartzite and Limestone (4 and 3), with associated Appin Phyllite (2), which are mapped at the northern margin of Pl. IV.

The *Gleann an Fhiodh Synform*, north of Pl. IV, probably includes the Appin Quartzite where crossed by the 1500 ft contour shown on Sheet 53 and the conspicuous Appin Limestone and Phyllite outcrop to the north-west.

The *Beinn Bhàn Synform*, still further north, probably includes the outcrop of Appin Quartzite half a mile east of Fraochaidh, and the tongue of Appin Phyllite that separates this outcrop from the eastern branch of the Ballachulish Slide.

C. T. C., E. B. B.

Lower Glen Creran and Glen Ure.—This sub-district corresponds with the area mapped in Pl. IV, overlapping with the previous sub-district in regard to Easan Diblidh and Allt Coire Mulrooney. As shown on its margin, Pl. IV extends from Taravocan southwards into one-inch Sheet 45 (Geol.). Unfortunately the Geological Survey Sheet 45 is only available in an uncorrected edition, first printed in 1907.

Before proceeding to detail let us take note of the outstanding structural features presented in this plate. We have on previous pages traced the outcrop of the core of the Ballachulish Fold, as marked by Ballachulish Limestone (6) and younger formations (5-2), from the Stob Bàn ridge above Glen Nevis (p. 47) to where it enters Pl. IV north of Ellerie. South of this, Pl. IV shows how the core outcrop on reaching Loch Creran swings back to the north-east until cut off by the Cruachan Pluton in Glen Ure. It also shows that the Ballachulish Slide swings round in exactly the same manner always separating the Ballachulish Core from a great outcrop of banded Leven Schists. These latter, as we have already seen, connect northwards (apart from disruption by the Ballachulish and Mullach nan Coirean Plutons) with the basement Leven Schists of the Stob Bàn secondary synform (p. 49).

Let us give a local name, Loch Creran Fold, to the fold responsible for the sharp deflection of outcrops, shown in Pl. IV. It must be a secondary fold, in the sense that it is obviously later than the Ballachulish Slide. A glance at Sheet 53 suggests that it is essentially identical with the secondary Stob Bàn Synform, so clearly exposed 16 miles to the north-north-east. We propose to show that this correlation is correct. All that is required is to demonstrate that the Loch Creran secondary fold is synformal.

The only alternative is to suppose that the Loch Creran Fold does not have a gently inclined axis, but is a torsional fold about a steep axis ; in which case it has no analogy with the Stob Bàn Synform.

We shall first give strictly local evidence under headings (1) to (3) ; and this proves highly suggestive though not conclusive. We shall then, under heading (4), supplement our local evidence by looking eastwards, when all becomes clear. The Loch Creran Fold is undoubtedly a synform.

(1) Let us start with the upper limb outcrop of Ballachulish Limestone (6), which reaches south-south-west from Allt Coire Mulrooney past Fasnacloich and the post office. On reaching Loch Creran it turns to go by Taravocan and the mapped sheepfold further east, and so reaches Glen Ure. On both sides of the Loch Creran Fold, dips are directed more or less north-westwards, but on the north-west side they seem to be significantly steeper than on the south-east. If this appearance is not misleading, the Loch Creran Fold must obviously be a synform.

(2) In the limestone outcrop we are considering, the appearance of dips on the north-west side of the Loch Creran Fold being steeper than those on the south-east is strengthened by the relative narrowness of the outcrop on the north-west side compared with the south-east. This argument would be conclusive in simpler country, but not here where the thickness of formations is largely influenced by slides.

(3) The Leven Schists in the heart of the Loch Creran Fold are seen just west of Taravocan to pitch gently north-eastwards. This affords very strong confirmatory evidence that the Loch Creran Fold is a synform. On the other hand, in complicated ground half a mile south of Taravocan, pitch is very steep and more often than not towards the south. Taken by itself appearances here suggest that the Loch Creran Fold is a torsional fold with a very steep axis. There is, however, no need to regard this last evidence as more than a symptom of irregular complexity.

(4) The evidence set out under heading (1) in favour of the synformal nature of the Loch Creran Fold becomes conclusive if it can be demonstrated that the Ballachulish Limestone between Taravocan and Glen Ure is passing *on a regional scale* under the Leven Schists that outcrop to the north-west. Fortunately there is no doubt whatever that such is the case. The Leven Schists concerned form part of a great spread, furnishing what we have often called the "cover," which, as Sheet 53 shows, reaches eastwards, through Leac Bharainn, Sgòr na h-Ulaidh, Meall a'Bhuiridh and Beinn Maol Chaluim to the lavas occupying the cauldron-subsidence of Glen Coe (Section BB, foot of Sheet 53 ; and Fig. 7, G,H). In this extensive area, which measures several miles whether considered from west to east or from north to south, the Leven Schists function as a thick moderately inclined layer. The top of this layer is defined by caps of Glen Coe Quartzite on Beinn Fhionnlaidh and Beinn Maol Chaluim, north-west of Glen Etive, and Stob Dubh, south-east of the same. The bottom of the layer is defined by the emergence of Ballachulish Limestone between Taravocan and Glen Ure, and again in the Windows of Etive, that is in Gleann Chàrnan, Gleann Fhaolain and Glen Etive. As Pl. IV and Sheet 53 show, before the band of Ballachulish Limestone we are considering reaches the Cruachan Pluton in Glen Ure, it has come to rest directly on the Ballachulish Slide. In the more easterly exposures, fur-

nished by the Windows of Etive (Fig. 7, G,H), this relationship continues ; but more information must be reserved for our discussion of the Glen Coe to Glen Etive district (I, p. 83).

Before proceeding to detail there is another important structural feature of Pl. IV to which attention may be drawn. We have already explained that from the northern limit of this map south to Easan Diblidh the Ballachulish Fold-Core is represented by outcrops which follow one another from west to east as follows : Ballachulish Limestone and Slates (6, 5, between two branches of the Ballachulish Slide) ; Ballachulish Slates, Appin Quartzite, Limestone and Phyllites (5, 4, 3, 2, between the eastern branch of the Ballachulish Slide and the Sgòrr a' Choise Slide) ; and Ballachulish Limestone (6, between the Sgòrr a' Choise Slide and the cover Leven Schists). We have also pointed out that in this locality, everything lying between the east branch of the Ballachulish Slide and the Sgòrr a' Choise Slide may with fair certainty be referred to the Sgòrr a' Choise Fold. Now if we look at Pl. IV south of Taravocan we recognise exactly the same succession of outcrops from south to north as we have just detailed in the Easan Diblidh, or better in the Allt Coire Mulrooney area, from west to east. It is, however, remarkable that the Ballachulish Core in these south-easterly exposures should be stratigraphically fuller than it is to the north-west between Easan Diblidh and Loch Creran. It will be remembered that the Ballachulish district shows clearly that the Ballachulish Fold closes towards the south-east. It therefore seems necessary to admit that the extra formations, as we may call them, south-east of Taravocan, have squeezed through the core rocks exposed north-west of Fasnacloich, the post office and Loch Creran.

The difficulty just described is purely local. In all outcrops of the Ballachulish Core from Allt Coire Mulrooney northwards to Loch Leven there is a fuller stratigraphical complement than in Glen Ure, Glen Coe and the Windows of Etive.

We now turn to local detail :

All the *foundation Leven Schists* (7′) of the north-west corner of Pl. IV are of the banded type characteristic on a large scale of the older part of the formation in the Kentallen-Appin district, p. 44. They are in fact largely composed of bands of impure quartzite. Across Loch Creran, eastwards, their character is considerably blurred by contact-alteration ; but it is clear that in this direction, as they approach the Cruachan Pluton, they contain an increasing proportion of grey mica-schist hornfels.

Glen Coe Quartzite (8) is mapped in Pl. IV as splitting the basement Leven Schists south of Glen Ure. Its structural position with reference to the Ballachulish Slide corresponds with what is found at Tom Meadhoin and Mam na Gualainn (Section A, Sheet 53 ; Figs. 8, 9, pp. 50, 51) and the Windows of Etive (Fig. 7, G, H, p. 48) ; but its lithological character is different. Elsewhere in Sheet 53 (but probably not in Glen Strae to the south-east, see Bailey and Macgregor, 1912, p. 172) the Glen Coe Quartzite is always fine-grained. Here, however, it is gritty with large and abundant grains of quartz and felspar. On character alone it might be correlated with the Appin Quartzite, but this is ruled out by a banded passage zone linking with the Leven Schists alongside. There can be no question of a misleading mechanical admixture, for many of the semipelitic layers are thickly strewn with big detrital grains.

The *cover Leven Schists* (7) of the north-east corner of Pl. IV, reaching south-west to Taravocan, are very different from the basement or foundation Leven Schists (7′) in that they are of the purely pelitic type characteristic on a very large scale of the younger portion of the formation in the type outcrop north of Loch

Leven (p. 40). The dissimilarity is of course due to displacement along the Ballachulish Slide.

Once more the contrast between the lower and upper limbs of the Ballachulish Fold also affects markedly (though not everywhere) the representation of the *Ballachulish Limestone* (6): in the lower limb the dark pure portion is generally all that is preserved, often in association with *Ballachulish Slates* (5) ; in the upper limb the pale impure portion is practically universal. The contrast here depends upon the conjoint operation of the Ballachulish and Sgòrr a' Choise Slides.

Let us start with the *lower limb*. Where this enters Pl. IV from the north, the Ballachulish Slide is double and its two branches embrace two bands of dark pure *Ballachulish Limestone* separated by an outcrop of *Ballachulish Slates*. This arrangement clearly continues with minor changes for a mile and a half. Further south-east, Ballachulish Limestone is very seldom seen along the north-west branch of the Ballachulish Slide, though three narrow strips, dark and pure, have been mapped in this position at localities numbered (6) on Pl. IV. The Ballachulish Slates continue ; but in a stream that flows down past the post office they join with a more south-easterly outcrop of the same formation, and this renders the south-east branch of the Ballachulish Slide temporarily unmappable.

It is thought, however, that the Ballachulish Slide continues double right down to Loch Creran. The succession of outcrops from west to east, crossed obliquely by the coastline, is as follows :

Banded basement Leven Schists—*at structural base*
Lower branch of Ballachulish Slide
Ballachulish Limestone, dark, pure, very thin
Ballachulish Slates, quarried for wall-building
Ballachulish Limestone, dark, pure, thicker, burnt for lime
?*Upper branch of Ballachulish Slide*
?Appin Phyllites, non-calcareous schist, very thin
?Appin Limestone, white limestone, very thin
?*Sgòrr a' Choise Slide*
Ballachulish Limestone, pale calcareous schist, thick—*at structural top*

In Plate IV the above queried interpretations are accepted ; but, owing to scale, no attempt can be made to represent the thin strip of probable Appin Phyllite and Limestone, so that the upper or south-east branch of the Ballachulish Slide is shown by the same heavy line as the Sgòrr a' Choise Slide.

To the east, across Loch Creran, the Ballachulish Slide is essentially single for about a mile, without any certain outcrop of Ballachulish Limestone or Slates along its course—a narrow local strip of calc-silicate-hornfels, though numbered 3 on Pl. IV, may perhaps be Ballachulish Limestone. Then turning east the slide resumes its double character, and encloses outcrops of Ballachulish Limestone and Slates with, at first, just the same arrangement as at the northern margin of Pl. IV. Exposures are excellent between a right-angle bend in a wall half a mile south of Taravocan and a fault that runs north-east to the sheepfold shown in the map : the limestone is dark marble, looking very like the dark pure portion of the formation as seen elsewhere outside contact aureoles ; the slates are represented by black pelitic hornfels spotted with cordierite.

East of the sheepfold fault things are different, for Ballachulish Limestone is mostly confined to the impure older portion of the formation (altered to calc-silicate-hornfels), and, in sympathy, Ballachulish Slates are wanting. The mapping in Pl. IV of Allt Buidhe is only approximate. Valley bottom exposures are poor except in the stream bed, and secondary folding is unusually complex. It is almost certain that Appin and Ballachulish Limestones are here slid together, as indeed they are in the relatively simple ground west of the fault. The apparent conjunction of the two limestones along Allt Buidhe is seen 200 yards upstream from the fault, where a second sheepfold, not shown on Pl. IV, serves as a useful landmark. Less than 100 yards to the south-east, unmistakable dark Ballachulish Limestone (marbled) outcrops in a hollow, while in the stream itself there are exposures of pale marble which have the appearance of contact-altered Appin Limestone. Pl. IV includes both occurrences (ornamented as Ballachulish Limestone) as lying between two branches of the Ballachulish Slide ; and six hundred yards further upstream undoubted Ballachulish Limestone is seen again. The outcrop allotted to this formation in Pl. IV, northwards from Allt Buidhe to the margin of the Cruachan Pluton, consists of a great thickness of calc-silicate-hornfels with minor outcrops of dark-grey marble. Its correlation as Ballachulish Limestone cannot be questioned ; and it obviously lies between two branches of the Ballachulish Slide.

These two branches must have come together again where for a short space cut off by the Cruachan Pluton, since the slide on reappearing for a couple of miles is either single or substantially so. Ballachulish Limestone has only been recognised along the slide in this part of its course in confluent streams draining towards Glen Ure House. It here consists of calc-silicate-hornfels and is about 40 feet thick, and its position is merely indicated by the number 6 on Pl. IV.

The *Ballachulish Limestone* of the *upper limb of the Ballachulish Fold* west of Glen Creran can readily be traced from Allt Coire Mulrooney, near Ellerie, to the head of Loch Creran. In this part of its course it is, owing to the Sgòrr a' Choise Slide, almost entirely represented by pale grey, very impure calcareous schist with occasional outcrops of pale limestone. The pure dark portion has in general been entirely cut out.

A trifling exposure of pure dark limestone does, however, occur on the eastern border of a phyllite outcrop mapped west of the post office in Pl. IV. The locality is 200 yards north of where this phyllite border reaches the road, half a mile south of the post office. The phyllite is problematical. It is grey with black streaks, and resembles part of the Appin Phyllites ; but it is difficult to believe that it is anything but a stratigraphical intercalation in the impure Ballachulish Limestone.

The Ballachulish Limestone in the upper limb of the Ballachulish Fold east of Loch Creran is practically always in the condition of calc-silicate-hornfels. Beds too pure to yield this product are almost completely absent, cut out here again by the Sgòrr a' Choise Slide.

Let us now turn our attention to the *formations younger than the Ballachulish Limestone*, whose outcrops intervene *between the upper branch of the Ballachulish Slide and the Sgòrr a' Choise Slide* ; and let us start on the west side of Glen Creran.

At the northern edge of Pl. IV the formations concerned are *Ballachulish Slates* (5), *and Appin Quartzite* (4), *Limestone* (3) *and Phyllite* (2). We have already seen how the outcrop of these formations narrows in Easan Diblidh, with omission of the Ballachulish Slates (p. 63). A mile further south-west, as shown in the post office stream, the diminution continues, and all three Appin formations have disappeared, though Ballachulish Slates have come in again. Another mile to the south-west, at Loch Creran, we think we can identify Appin Limestone and Phyllite in a strip too narrow to show on Pl. IV ; but that is all (p. 66).

East of Glen Creran an almost continuous outcrop of *Ballachulish Slates* (5) borders the Sgòrr a' Choise Slide, corresponding exactly with the outcrop due north of Ellerie. It is very narrow near the alluvium at the head of Loch Creran, and about half a mile further north-east it temporarily disappears, evidently as a result of sliding. When, a little further east, it comes in again its black slates have been transformed to black hornfels spotted with cordierite. East of the fault that crosses by the sheepfold of Pl. IV this black hornfels is extremely prominent and gives rise to a sombre row of crags, conspicuous even from a distance.

The *striped transition zone of the Appin Quartzite* (4) which follows is much less definite in its characters, and one cannot, in the contact aureole, always distinguish it with certainty from parts of the Appin Phyllites or the banded portion of the Leven Schists. Its outcrop, however, in most cases is limited by hornfelsed black slate on the one side and gritty quartzite on the other. In the burn flowing north-west to the sheepfold the striped zone is shown in Pl. IV as terminating somewhat abruptly against banded Leven Schists. The mapping naturally becomes rather difficult in this case, but fortunately the banded Levens here no longer closely approach the striped division of the Appin Quartzite in character, for they contain a large proportion of grey pelitic mica-schist hornfels.

The *massive gritty division of the Appin Quartzite* (4) is of great assistance to the mapper, for it retains its normal characters even close to the Cruachan Pluton. It is a massive pure-white quartzite with big detrital grains of quartz and felspar. The value of the quartzite is particularly evident in the Allt Buidhe glen, where its outcrop, taken in conjunction with that of the hornfelsed Ballachulish Slates, very clearly defines the essential features of an unusually intricate bit of structure. It is noteworthy that almost all the dips seen in the Allt Buidhe district are extremely steep, and that the form of outcrops is not appreciably influenced by topographic features of the magnitude of the Allt Buidhe valley.

The *Appin Limestones* (3) *and Phyllites* (2) come next in order. Narrow outcrops of calc-silicate-hornfels have been noted at the eastern margin of the Balliveolan outcrop of Appin Quartzite, and are referred with some hesitation to the Appin, rather than the Ballachulish, Limestone position. Along the southern margin of the next outcrop of Appin Quartzite, about half a mile south of Taravocan, a band of marble, or a corresponding hollow, is constantly seen. In colour this marble may be white, pinkish or grey. A grey specimen, taken from close to the fault which leads down to the sheepfold, was found to contain forsterite (S 17310), indicating its original dolomitic character. Another specimen, however, from the same band further west showed no forsterite (S 17309). Across the fault the gritty Appin Quartzite is again frequently bounded on the side remote from the striped zone by a band of marble, as shown in Pl. IV. A grey marble, from the edge of the quartzite at the top of the declivity leading down to the stream that flows north-east to the sheepfold, has proved on examination to be particularly rich in forsterite and green spinel (S 17311). There can be no doubt whatever as to the correctness of the correlation of all these marginal outcrops of marble with the Appin Limestone. We shall return in a minute to what we regard as Appin Limestone separated by a stratigraphical intercalation (numbered 2 on Pl. IV) from this marginal band.

The *Appin Phyllites* east of Glen Creran belong almost wholly to this supposed intercalation. Here in the aureole of the Cruachan Pluton they are practically indistinguishable from the striped zone of the Appin Quartzite—just as at Kentallen and in Allt Giùbhsachain on the two sides of the Ballachulish Pluton. There is a further difficulty in that the banded Leven Schists near Loch Creran are also of very similar appearance. In fact in mapping certain hornfelses with quartzite ribs as Appin Phyllites one has to be guided to a large extent by their relations to more easily recognisable formations on either side. There is, however, good internal evidence for assigning the banded hornfelses half a mile south of Taravocan to the Appin Phyllites, for various exposures show alternating beds of impure calc-silicate-hornfels, phyllite-hornfels and quartzite, an assemblage very reminiscent of parts of the Appin Phyllites elsewhere.

The recurrence of *Appin Limestone* some little way in from the Appin Quartzite margin of the Appin Phyllites is a feature often noted further north. Near the southern margin of the Appin Phyllite outcrop just described there is a thick bed of irregularly weathering white marble (sometimes grey), with dark streaks. It is first seen north-west of a wall half a mile due south of Taravocan, and can readily be followed thence to the fault about a mile further east. Two specimens (S 17307-8) examined contain no forsterite, but this does not in any way disprove the Appin correlation. Across the fault, as already explained, the white marble is conspicuous in Allt Buidhe (p. 67). Both east and west of the fault, it often contacts undoubted Ballachulish Limestone on the side remote from the Appin Phyllite outcrop.

One point remains. East of Glen Creran there are very numerous small sheets of compact *hornblende-schist*. Only a small proportion of them are shown in Sheet 53, and none at all in Pl. IV. Scattered examples occur as far east as Beinn Fhionnlaidh, where a narrow porphyritic example cuts Glen Coe Quartzite near a small lochan close to the margin of the Cruachan Pluton. The main concentration is near Glen Creran, and straddles the outcrop of the Ballachulish Slide. It is clear from this that their intrusion post-dates the development of the slide. Their foliation, which is often very pronounced, is quite possibly connected with the secondary folding responsible for the Loch Creran Synform. E. B. B.

G. GLEN COE

Introduction.—The schist geology of Glen Coe is the counterpart of that just described east of Glen Creran (*cf.* Fig. 10 and Pl. IV), in that it shows the outcrop of the Ballachulish Core and Slide, in the south-east limb of the Stob Bàn—Loch Creran secondary synform, swinging eastwards cross-country under the influence of pitch. The pitch direction at Glen Coe is south-west and at Loch Creran north-east. Between lies the great pitch-depression of Glen Creran (Fig. 17, p. 112).

Moreover the schist geology of Glen Coe is the direct continuation of that exposed between Callert House and Callert Cottage, just across Loch Leven (Figs. 8, 9, pp. 50, 51). Stated in terms of shore exposures, its outstanding feature is the reappearance of the Ballachulish Slide at a boathouse north of Glen Coe House (Fig. 10), two and a half miles east of where this slide goes underground at St. John's Church (Pl. III; Fig. 7, F, pp. 55, 48). This corresponds precisely with the reappearance of the same slide east of Callert, one and a half miles east-north-east of where it goes underground in the promontory marked by a black cross in Fig. 8. It will be remembered that recognition of the synformal disposition of the Ballachulish Slide in the Callert district follows from consideration of the Stob Bàn Synform—or alternatively of the Tom Meadhoin Antiform; and that a similar conclusion is deducible in the Glen Creran district from consideration of the Windows of Etive. Altogether the reader is advised to turn to the discussions starting on pp. 47, 64. More local, but less direct, evidence on the same point is afforded in the exposures of the Beinn Bhàn Synform and of the antiform separating this structure from the Gleann an Fhiodh Synform (p. 58). E. B. B.

Below is given a brief account of the geology of the Glen Coe district as a whole, such as can be followed at home with the help of Sheet 53. Then comes detail regarding the Loch Leven shore section north of Glencoe House, to be followed by rather elaborate notes of an excursion up Glen Coe by the old road to Loch Achtriochtan and back by the new (Fig. 10). After this, separate descriptions are supplied of exposures at Meall Dearg and Coire Mhorair, further east and just across the ridge that bounds Glen Coe to the north.

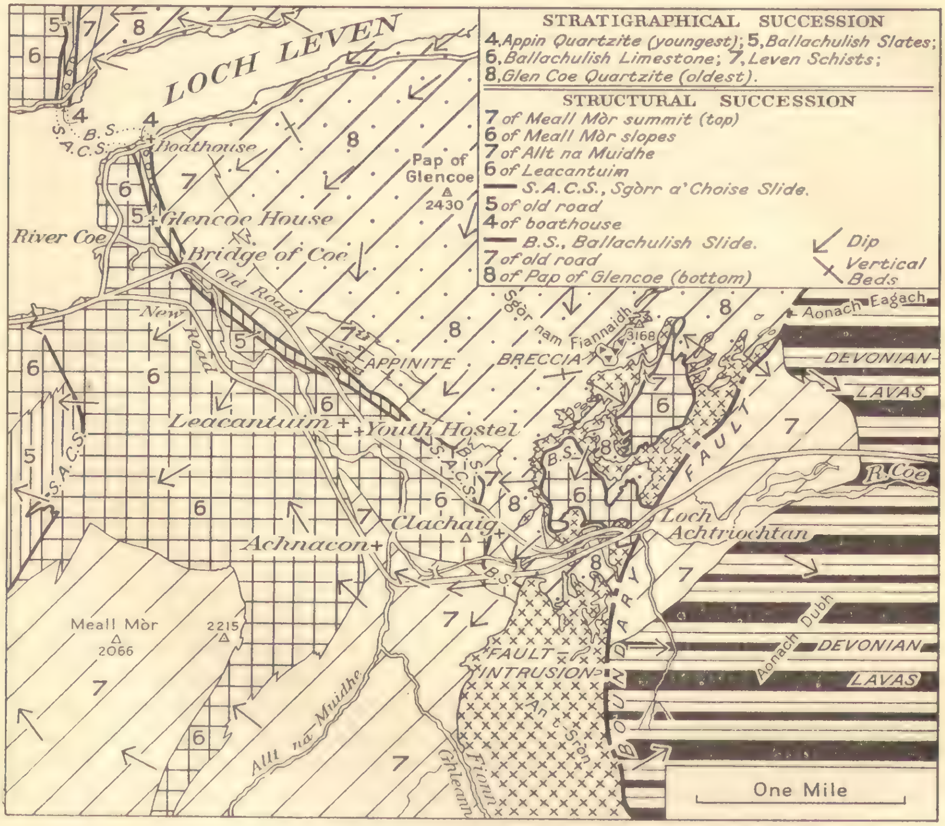


FIG. 10. Map of Lower Glen Coe

General.—On the shore north of Glencoe House banded Leven Schists (7) are brought by the Ballachulish Slide (B.S.) into contact with Appin Quartzite (4), which includes partial representatives of both its massive and its striped zones. Next westwards follows a thin band of Ballachulish Slates (5) ; and then, through the intervention of the Sgòrr a' Choise Slide, comes very slightly calcareous schist belonging to the middle part of the Ballachulish Limestone series (6)—for detail see p. 72.

The Appin Quartzite does not continue far inland along the Ballachulish Slide, while at the same time a less impure portion of the Ballachulish Limestone inserts itself along the Sgòrr a' Choise Slide. This is the general state of affairs for two miles south-east from Bridge of Coe. The less impure part of the limestone series corresponds with the grey micaceous limestone mapped in Fig. 8 south-east of Callert House.

At Clachaig Hotel the thin band of Ballachulish Slate fails, and banded Leven Schists (7) come into direct contact with impure Ballachulish Limestone (6), here in the condition of calc-silicate-hornfels (S 11048-9, 15871-2). The omitted unbanded portion of the Leven Schists is estimated at a couple of thousand feet thick. The section is an exact foretaste of what will be described in the Windows of Etive (p. 85), except that at Clachaig the Ballachulish Limestone (calc-silicate-hornfels) is considerably thicker.

East of Clachaig and north of Loch Achtriochtan, in the vicinity of the Cauldron-Subsidence of Glen Coe, the Ballachulish Core climbs up to the very summit of the ridge confining the glen, and is represented on its slopes by two large isolated outliers. The average inclination of the underlying Ballachulish Slide is 20° S.E., whereas, from Loch Leven to Clachaig, it is probably steeper and is consistently directed S.W. The swerve of strike may be partly due to sinking towards the cauldron-subsidence, but mainly it marks the S.E. limb of the Loch Leven Antiform of p. 23. A third, minor outlying patch has been located north of Meall Dearg (p. 80). In all three, marginal Ballachulish Slates are generally wanting ; and banded Leven Schists below are more or less cut out. Accordingly the core-rock is almost wholly calc-silicate-hornfels (often little more than baked phyllite), and it rests very closely upon Glen Coe Quartzite except that, on the Glen Coe slopes, coarse porphyrite (Fault-Intrusion of Glen Coe) usually follows the plane of junction. The Meall Dearg exposure, though outside the main Boundary-Fault, lies just south of a subsidiary branch (Fig. 23, p. 156).

On crossing the main Boundary-Fault into the Cauldron-Subsidence we find in Coire Mhorair (p. 80) that Ballachulish Slates reappear, furnishing a narrow outcrop, while Ballachulish Limestone is developed in force, emerging from beneath unconformable lavas of the Glen Coe series (Fig. 24, p. 158). Without doubt the Ballachulish Slates and Limestone of Coire Mhorair belong to the Ballachulish Core, and equally certainly they pass (while hidden by later lavas) beneath greenish-grey phyllites that are well displayed to the south-west either side of Loch Achtriochtan (Fig. 7, E, F ; Fig. 10). It is obvious that these phyllites, thrown down by the Boundary-Fault of the Cauldron-Subsidence, must structurally overlie the Ballachulish Limestone of the outlying patches outcropping just across this fault to the north-west. Obviously too, they form part of the great cover-spread of Leven Schists, which, outside the Cauldron, follows to the south of Ballachulish Limestone towards Glen Etive and Glen Creran.

H. B. M., E. B. B.

Two facts of first class importance follow from examination of the *metamorphic condition* of these phyllites. The first is that they have escaped the contact-metamorphism characteristic of all neighbouring schists surrounding the cauldron-subsidence—this is a matter to be discussed in chapter xii. The second is that (making abstraction of contact-metamorphism) their regional metamorphism is manifestly lower than that of the Leven Schists belonging to the same great structural layer in its exposures close at hand outside the Cauldron-Subsidence. The safe inference is that regional metamorphism in this district decreased upwards, and that the great downthrow of the cauldron-subsidence has juxtaposed markedly different grades of regional metamorphism. The local detail, easily checked, is reserved for pp. 78-9. H. B. M.

A word of personal explanation is required. In the first edition of this memoir no mention is made of the contrast of *regional* metamorphism described above. Actually Maufe fully recognised its reality and significance, and often referred to it in conversation. Unfortunately he left for South Africa without supplying full notes for the memoir. The writer, to whom it fell to make good the deficiences, had no opportunity to check this particular point in the field ; and, fearing the possibility of a mistake in a locality where contact-metamorphism complicates the issue, he left Maufe's views unrecorded in print. Confirmation, however, has been supplied in a paper by G. L. Elles and C. E. Tilley, to whom Maufe's observations had been communicated. They found the field relations as stated, though their own interpretation of evidence in neighbouring districts led them to expect the exact opposite (1930, p. 641) ; and the writer has since satisfied himself on the ground that Maufe was right. For similar evidence at Ben Nevis, see p. 179.

E. B. B.

All that remains in this general account of Glen Coe is to say a few words about the relations of the Ballachulish Limestone of the glen to what we have called the cover-spread of Leven Schists. This cover-spread is divided for four miles south-westwards from Glen Coe by a tongue of Ballachulish Limestone (calcareous schist) constituting the upper half in this neighbourhood of the Ballachulish Core. Above lie the Leven Schists of Meall Mòr (Fig. 10), while below come those of Allt na Muidhe, resting in turn quite clearly on the lower half of the Ballachulish Core as developed east of Leacantuim. Fig. 10 supplies minor rectifications of mapping, not available for the 1948 edition of Sheet 53, and these serve to emphasise the tectonic beauty of the recumbent fold displayed between Clachaig and Meall Mòr with its limestone core outcropping in the north-west slopes of the glen holding Allt na Muidhe. H. B. M., E. B. B.

Now let us turn to detail.

Loch Leven Shore North of Glencoe House.—The section to be described lies close to, or along, the south-bank road to Kinlochleven, shown in Fig. 10, p. 70. The road here is, for half a mile, winding and wooded, and motorists visiting the section should park at one or other end, for traffic includes buses and lorries. The landmark is a boathouse about midway in the danger zone. The following measurements were made with a tape along the road from east to west. Very roughly they correspond to cross-strike figures :

	Yards
Boathouse stands on twisted and broken banded quartzite and mica-schist belonging to the banded edge (here quite broad) of the basement Leven Schists (7)	—
Gap through which, according to inland exposures, the *Ballachulish Slide* must run	53
Gritty Appin Quartzite (4), best seen on shore	8
Striped zone of Appin Quartzite (4)	30
Gap	55
Black Ballachulish Slates (5), well seen at road but not on shore	29
Gap including *Sgòrr a' Choise Slide*	32
Impure, grey, slightly calcareous schist belonging to the middle part of the Ballachulish Limestone (6), exposed for a long distance along both road and shore	—

Road Excursion, Glen Coe to Loch Achtriochtan.—Since Glen Coe is so often visited the following roadside description is not confined to schist geology, so that to appreciate the significance of some of the topics introduced a reader may have to consult later chapters.

Lower Glen Coe has two roads, both maintained in good condition until they meet at Loch Achtriochtan (Fig. 10). The old road, north-east of the river, follows approximately the course of the Ballachulish Slide, so that along it one has plenty of opportunity to hammer rocks near this critical position. On the other hand it hugs too closely the north-eastern slope of the glen, and is too thickly wooded, to do full justice to the geological landscape. In this respect the new road is exceptionally happy, and the views it affords of major structures are wonderfully impressive. The main schist groups concerned, Glen Coe Quartzite (8), Leven Schists (7) and Ballachulish Limestone (6), have sufficiently distinctive scenic expression to enable outcrops and field relationships to be followed from a distance with the help of the one-inch geological map or Fig. 10 (which includes some minor corrections).

The excursion, as outlined, starts from and returns to Loch Leven, which helps in the appreciation of a very complicated stretch between Clachaig Hotel and Loch Achtriochtan. Visitors arriving at this loch in the opposite direction, *from the east*, should be able to grasp the main features of the Cauldron-Subsidence with its Boundary-Fault and associated Fault-Intrusion as illustrated in Fig. 20, p. 133 ; but they may easily lose themselves if they attempt, without further introduction, to disentangle the local schist story, the evidence for which has been cut to pieces by the Glen Coe Fault-Intrusion and by somewhat later north-east dykes. They are therefore advised, after a halt at the west end of Loch Achtriochtan, to pass on fairly quickly beyond scattered outcrops of the Fault-Intrusion to a foot-bridge across the Coe close to the new road south-south-east of Clachaig Hotel, and to begin their detailed examination with Stage 2 (p. 75) followed by Stages 3-7.

1. The *first stage* of the excursion, as planned from the west, lies between Bridge of Coe and Clachaig Hotel ; but the coastal exposure described above (p. 72) at the boathouse north of Glencoe House (County Maternity Home) should, if possible, be studied in advance, along with the closely connected Callert evidence across Loch Leven (p. 50).

Bridge of Coe lies at the east end of Carnach, often called Glencoe village, situated on a delta which the Coe built out post-glacially into the sea when high water stood at what is now 35 ft above O.D. The river beneath the bridge shows Ballachulish Limestone (6) in the form of a contorted phyllitic grey limestone, a good deal purer than anything seen at the boathouse (p. 72). On the east, hill slopes rise to the summit of the Pap of Glen Coe, 2430 ft. Much of the intervening steep hillside is thinly covered by moraine, but it is clear that the greater part is fashioned out of quartzite, the Glen Coe Quartzite (8). This latter dips S.W. at about 75°, furnishing a complicated example of pitch (p. 23).

The limestone is separated from the quartzite by a narrow composite belt consisting of black schist, measuring about 50 yards across, followed to the north-east by grey phyllite (or mica-schist) with quartzite bands, about 400 yards wide. The black schist just mentioned is well seen at the roadside, 250 yards E. of the gate into the grounds of Glencoe House. The boathouse and Callert evidence proves conclusively that it is a reduced representative of the great Ballachulish Slates quarried in force only two miles to the west. Also, the boathouse, Tom Meadhoin (p. 52) and Stob Bàn (p. 47) evidence proves equally surely that the accompanying grey phyllitic mica-schist belongs wholly or almost wholly to the banded portion of the Leven Schists.

In their original mapping Peach and Maufe traced the Glen Coe black schist as a narrow band persisting almost to Clachaig Hotel ; and Maufe, at any rate, rightly regarded it as a possible reappearance of the Ballachulish Slate formation. He entertained this supposition at a time when as yet no one had dreamt of the existence of the Ballachulish Slide ; he approached the subject of correlation through his recognition of the problem presented by the three-sided nature of the type outcrop of the Ballachulish Limestone. This latter is bounded at Ballachulish

(Pl. III) by the great Ballachulish Slates, at Meall Mòr by the even greater Leven Schists, and at Bridge of Coe itself by the miniature Glen Coe black schist (Fig. 10). The writer remembers the incredulity with which he first heard from Maufe of the possible correlation of black Ballachulish Slates and Glen Coe black schists. He can therefore sympathise with newcomers to the district, who may feel inclined to dismiss it as absurd.

The black schist (Ballachulish Slate) seen 250 yards E. of the gate to Glencoe House, is in contact on its north-east margin with a banded group of grey phyllite or mica-schist, which carries some black seams and many interbeds of quartzite. It has not been possible as yet to decide whether this all belongs to the banded Leven Schists or whether a strip close to the black schist should be interpreted as part of the striped zone of the Appin Quartzite—undoubtedly present at the boathouse. In other words it is as yet uncertain whether the Ballachulish Slide lies exactly along the north-east margin of the black schist or a few yards further north-east. What is easy to appreciate is that the whole of the Ballachulish Limestone and of the immense unbanded portion of the Leven Schists is here missing between the Glen Coe black schists (Ballachulish Slates) and the Glen Coe Quartzite of the Pap.

The Coe runs close alongside the road at this point and furnishes further exposures of the black schist. Upstream an alluvial strath intervenes between river and road. At first the latter traverses thin moraine with a very few exposures of banded Levens. Then it crosses two great rubble cones discharged by tributary streams. Such cones are a characteristic feature of the north slopes of Glen Coe. The two of the present locality have come from gorges initiated along shatter-belts due to unimportant faulting—another common circumstance.

Beyond the deltaic cones the road for a short distance is bounded to the north by well-exposed banded Leven Schists. Very soon, however, at a gentle curve to the left, it runs for 250 yards at the foot of a dark wooded slope, mapped as black schist. Specimens can be collected from two small neighbouring intrusions of appinite. The more southerly lies in the black schist, and is crossed by a wall that runs up the hillside close to a minor stream. The more northerly (S 11036-7), with aplitic veins (S 11906) and associated " granite " (S 11038), has intruded banded Levens and is exposed 50 to 300 yards E. of the wall. The hornblendes of the more northerly appinite are sometimes three inches long.

At the next gentle bend, this time to the right, the road passes on to an exposed continuation of the phyllitic limestone (Ballachulish Limestone) last seen at Bridge of Coe, now a mile distant. The exposures of the calcareous group form picturesque mounds and are no more than openly wooded. They are at first confined to the north of the road, but soon extend to the south, where we find Leacantuim farm and a Scottish Youth Hostel, and, further on, two artificial fish-ponds. The famous Signal Hill, marked by a triangle on Fig. 10 just S.W. of Clachaig Hotel, is the most conspicuous of these calcareous knolls. Upon it, according to unconfirmed tradition, a fire was kindled to advertise zero hour for the 1692 massacre.

Walkers, as soon as they realise they have reached the Ballachulish Limestone, should temporarily leave the road and follow instead the margin of this formation, which for the next mile lies a little to the north. Even those who are tied to transport should park and carefully examine the rocks of the locality. A minor point of interest is that there is some impure grey carbonaceous limestone studded on its weathered surface with roughly isometric crystals of albite, measuring half a centimetre across and packed poecilitically with calcite granules (S 39694)—a very unusual mineral development for Scotland. This albitic limestone carries rather smaller porphyroblasts of phlogopitic biotite. The neighbouring banded Levens occasionally show garnet.

Of much more importance is the fact that the Ballachulish Limestone is separated from banded Leven Schists on the north-east by a shallow hollow in which exposures of the black or dark grey mica-schist (Ballachulish Slate horizon) can readily be found, sometimes containing garnet (Elles and Tilley 1930, p. 640). About a quarter of a mile east of the beginning of its exposures, this black schist can be seen firmly welded on to banded Leven Schist. Mere examination of the junction would not justify anyone in affirming, or denying, the presence of the great Ballachulish Slide, which must here separate the two formations. Three hundred yards west of Clachaig Hotel the Ballachulish Limestone crosses wholly to the south side of the road. Just about this point the Ballachulish Slate outcrop fails. It must reach the road, since it is represented by dark grey mica-schist on both sides of a fence immediately to the north ; but south of the road, exposures soon show that it no longer separates Ballachulish Limestone from banded Levens. The Ballachulish Limestone is here in the condition of calc-silicate-hornfels owing to the proximity of the Glen Coe Fault-Intrusion.

2. We have now reached the *second stage* where the geology of the glen centres naturally on Clachaig Hotel. The hotel itself stands on Glen Coe Quartzite dipping west at about 45°. In this direction the quartzite passes under banded Leven Schists whose outcrop measures some 75 yards across. They are mostly seen in a ragged plantation, where they are cut by an unusually large porphyrite dyke running for the time being north and south.

Back along the road, at a hundred yards north-west of the hotel, the plantation is bounded by a wall running S.W. If, leaving the road, one follows this wall for 75 yards, one traverses nothing but banded Leven Schists, until, just before reaching a gentle bend to the left, one finds these banded Levens passing under the calc-silicate-hornfels representative of the Ballachulish Limestone. (See chap. xviii for description of unusual specimens, S 11048-9, 15871-2). Here then we have one of the most easily located exposures of the Ballachulish Slide, cutting out the pure portion of the Ballachulish Limestone and the great unbanded portion of the Leven Schists.

The Clachaig exposures are duplicated at and near a foot-bridge over the Coe 300 yards S.S.E. of the hotel. We shall give this locality further attention in the sixth stage of our excursion, when we pass close by on the return journey along the new road. Meanwhile north of the hotel we see descending from the quartzite mountain of Sgòr nam Fiannaidh, 3168 ft, a stream that has etched a gorge, for long unclimbed. Here again is an example of the ease with which erosion can attack smashed rock along a minor fault. Debris, swept down to form a spreading fan, extends to the margin of the road.

East of the debris chute are crags of Glen Coe Quartzite, with perhaps some little that might be ascribed to banded Levens. The bedding is often obvious, and, in a general way, has an antiformal disposition with steep south-westerly pitch. Thus, while along the north slope of Glen Coe from the mouth of the glen to Clachaig dip has been steeply S.W., at Clachaig it swings round to the S.E. and continues so to the Boundary-Fault of the Cauldron-Subsidence.

The crags of quartzite overlooking the debris chute are surmounted by obviously softer rocks. These are calc-silicate-hornfels and represent Ballachulish Limestone riding on the Ballachulish Slide. What is seen from the hotel is merely the start of an extensive cake which reaches half a mile uphill and for the same distance eastwards to the mouth of Loch Achtriochtan. Superposition of the calc-silicate-hornfels on the quartzite is very clear in the view from the hotel ; but the actual junction is obscured by the fact (recognised by Peach) that it has on this, the north side of the glen, located an important irregular sill of the Glen Coe Fault-Intrusion. The Fault-Intrusion hereabouts is a coarse porphyrite, pink or grey, and it has flooded the quartzite (and banded Leven Schists) below the Ballachulish Slide, whereas it has scarcely entered the overlying calc-silicate. The probable cause of this relative impermeability is the felted texture of the calc-silicate, held together by minute needles of tremolite.

The irregular flooding of the quartzite by Fault-Intrusion is illustrated in an easily visited small quarry 200 yards E. of the hotel. A more interesting exposure is afforded by a pronounced little antiform seen 300 yards N.E. of the hotel (at Creag nan Gobhar, the Goat's Crag, on the 6-inch map). Here there are several irregular intrusions of Fault-Intrusion, which Peach (almost certainly correctly) held responsible for the antiform ; but to do justice to the evidence one must be prepared to spend a couple of hours and undertake a definite scramble.

3. The *third stage* is the final outward part of the excursion. It begins where the old road comes to the river bank a quarter of a mile east-south-east of Clachaig Hotel ; and it ends at Loch Achtriochtan. Until the Boundary-Fault of the Cauldron-Subsidence is reached the northern face of the glen is mainly occupied by calc-silicate-hornfels (Ballachulish Limestone) in two closely adjacent cakes that measure respectively half a mile by half and three-quarters of a mile by a quarter. These two cakes are plastered, as it were, on the steep hill side. We have already viewed the western margin of the more south-westerly cake when we stood in front of Clachaig Hotel. The northern tip of the more north-easterly extends to over 3000 feet above sea level where it reaches the summit ridge of Sgòr nam Fiannaidh. With a geological map to help, it is easy to recognise these two cakes in the local scenery (especially if one looks from the new road across the river). Both present what seems in the local setting a strangely smooth surface, due to the nature of their material uninterrupted by Fault-Intrusion. The surrounding ground occupied by Fault-Intrusion ramifying among quartzite and banded Levens offers strongly contrasted irregularity.

The pronounced south-easterly dip of the calc-silicate cakes would, if uninterrupted, provide a valley-bottom outcrop connecting with the broad band of Ballachulish Limestone that has been traced from Bridge of Coe to Clachaig. Actually, however, a gentle east-west antiform must run along the bottom of the glen, for most of the river exposures show rocks a little below the Ballachulish Slide. These consist of banded Leven Schists along with Glen Coe Quartzite, both irregularly cut by and impregnated with Fault-Intrusion. There are in addition later porphyrite dykes. The Glen Coe Fault-Intrusion here is coarse porphyrite or plutonic equivalent, grey (S 10307) or pink. At, and west of, a conspicuous salmon ladder it is grey ; while further upstream, 150 yards W. of the bridge that brings the new road across the Coe, it is pink and much resembles common types of the later N.E. porphyrite dykes. At the salmon ladder the grey Fault-Intrusion is seen in contact only with banded Levens ; whereas the more easterly pink outcrop separates banded Levens, downstream, from calc-silicate-hornfels, upstream. This last belongs to the first of the two hillside cakes. The following four exposures of the calc-silicate can easily be identified : (1) 100 yards downstream from the road-bridge, between the pink Fault-Intrusion of the river bed and the adjacent road (S 39692) ; (2) immediately downstream from the bridge and east of the pink Fault-Intrusion of the river bed ; (3) in a roadside quarry facing the bridge where the old and new roads meet (S 39693) ; (4) just above the road on the loch side, 300 yards N.E. of the bridge.

The quarry at the bridge exhibits a variety of rocks : at its east side is calc-silicate-hornfels ; further west, there is a broad pink porphyrite dyke which to the south furnishes the foundation of the bridge ; further west again is pink Fault-Intrusion, xenolithic and ramifying, the obvious continuation of the pink Fault-Intrusion of the river bed just across the old road. At one point in the quarry the Fault-Intrusion cuts a dark hornfelsed mica-schist, which is not calcareous and yet is unlike Leven Schist—it is probably much-altered Ballachulish Slate just above the Ballachulish Slide.

South of the river, hornfelsed mica-schist (S 39695), exactly like the probable much-altered Ballachulish Slate of the quarry, is seen in a cutting of the new road 50 yards W. of the bridge. This is followed westward by a 50-yard exposure of pink Fault-Intrusion on the southward continuation of the quarry and river outcrop. To the west again in the road cutting, as in the river, come banded Leven Schists. It is obvious that the quarry, river and new road exposures of pink Fault-Intrusion, separating, as they do, the more south-westerly cake of calc-silicate-hornfels from banded Leven Schists, must belong to the irregular sill that Peach mapped below the calc-silicate on the steep hillslope to the north.

4. The *fourth and furthest east stage* of our road excursion is located approximately at the western end of Loch Achtriochtan. Here we obtain the wonderful view of the south slopes of the glen depicted in Fig. 20, p. 133. We have reached the Boundary-Fault of the Cauldron-Subsidence of Glen Coe, and are looking at a natural cross-section, truly impressive. To the east are preserved downthrown Devonian volcanic rocks resting unconformably on much older phyllites (Leven Schists). Together these have sunk deep within the Cauldron-Subsidence. To the west we see An t-Sròn, made of a " granitic " Fault-Intrusion which in molten condition rose outside the Boundary-Fault as the rocks inside went down thousands of feet. We leave the Devonian lavas for later consideration in chapter xi ; but the Fault and Fault-Intrusion require further attention here, as also the schists.

The gorge marked " fault " with " chilled margin of granite " in Fig. 20 is easily identified. This gorge has been guided by shattering, which is of later date than the main faulting since it has broken the smooth chilled edge of the " granite " into fragments.

An independent point of interest is that the Boundary Fault changes course appreciably where the firm line representing it in the sketch (Fig. 20) passes downhill into an interrupted line. With the help of an air photograph it is easy to see that the attendant later shatter-belt continues downhill without this deviation, and crosses the old road just west of the bridge quarry, thence to continue for a mile up the north face of the glen, a conspicuous feature-maker. Similarly, shattering along the deviated line of the Boundary Fault, shown by a broken line in Fig. 20, continues uphill and is responsible for the erosion of the minor gorge appearing above the word " granite " in our sketch.

Mapping indicates that the deviated Boundary-Fault must pass through the River Coe practically where the latter leaves Loch Achtriochtan ; and actual fault-rock is here exposed just downstream from a foot-bridge. It is a dark, almost flinty rock, totally unlike anything else in the neighbourhood. Microscopic examination reveals that it (S 39696) has probably been derived by baking from flinty crush-rock (p. 160). Much of its substance seems to have been provided by comminution of the very impure Ballachulish Limestone that here margins the fault, but it retains no textural vestige of schistose antecedents. Minute grains of quartz are easily recognised, either in trains or more often isolated. An abundant matrix can be largely resolved by a high power into unorientated flakes of biotite and prisms of tremolite.

The " granite " that represents the Fault-Intrusion in An t-Sròn (Figs. 10, 20) has behaved very differently from the much more dispersed porphyrite versions of the same exposed in the River Coe and on the north slopes of the glen. Instead of being confined below the layer of calc-silicate-hornfels, it has burst through, high into the great cover of Leven Schists. It is full of quartzite xenoliths, and may perhaps have blasted its way explosively. Its eastern margin, let us repeat, is smooth and chilled against the downthrown lavas and phyllites within the cauldron, while its western margin is irregular and unchilled. In keeping, its contact-metamorphism is almost wholly restricted to the rocks outside the Boundary-Fault. This is easily checked by comparing the hornfelsed condition of the various groups of schist seen downstream from the road-bridge with the unhornfelsed state of the phyllites (Leven Schists) within the cauldron. The latter are conveniently sampled a quarter of a mile to the north-east, where the combined road leaves the shore of Loch Achtriochtan (S 39688).

The Loch Achtriochtan basin, two-thirds choked with alluvium, lies wholly on the phyllite outcrop. It is a shallow rock basin, overdeepened, as Maufe first pointed out, by selective glacial erosion. As a rule the phyllite has behaved as the most easily eroded rock of the vicinity. Fig. 20, however, shows a local contradiction, where phyllite knobs overlook adjacent fault-intrusion. In this case it is probable that with increasing bulk in An t-Sròn the Fault-Intrusion has succeeded in indurating a narrow belt of phyllite without notably changing its general appearance.

The effect of the Boundary-Fault on the distribution of regional metamorphism has already been discussed rather fully (p. 71). To appreciate it in the field one should compare the condition of the downthrown phyllites (S 39688), mentioned above, with that of garnetiferous mica-schists to be described below along the new road 500 yards W. of the footbridge S.S.E. of Clachaig Hotel (S 39690) and again at Achnacon farm (S 39689).

5. The *fifth stage* finds us going homeward by the new road as far as the foot-bridge over the Coe, S.S.E. of Clachaig Hotel. It repeats points already dealt with in stage (3) of the excursion —d, p. 79.

6. The *sixth stage* is based on the foot-bridge just mentioned. This lies close to the new road, and is built on Glen Coe Quartzite dipping 45° S.W. under banded Leven Schists. These in turn pass under calc-silicate-hornfels well exposed in a road-cutting, at the east end of which stands a conspicuous boulder. With these guides and with the help of Fig. 10, a geologist will probably be able to read the view spread out before him for a couple of miles. It affords one of the most spectacular illustrations of recumbent folding coupled with sliding that Scotland has to offer, in descending order as follows :

f. In the distance, unbanded Leven Schists (7) of Meall Mòr summit
e. Impure Ballachulish Limestone (6) of Meall Mòr slopes stretching S.W. from Achnacon
d. Unbanded Leven Schists (7) of Allt na Muidhe
c. Impure Ballachulish Limestone (6) of the road-cutting 300 yards from where we stand ; here it is calc-silicate-hornfels, but it continues as impure, unbaked limestone past Leacantuim to Bridge of Coe

BALLACHULISH SLIDE

b. Banded Levens (7) at our feet, crossing to the old road at Clachaig and continuing thence to the boathouse on Loch Leven
a. Glen Coe Quartzite (8) also at our feet, providing foundation to the foot-bridge and extending past Clachaig into the Pap of Glencoe

7. In the *seventh stage* a traverse from this foot-bridge S.S.E. of Clachaig along the new road past Achnacon to Loch Leven will allow us to sample all but the topmost item (*f*) of the above structural succession.

(a) The Glen Coe Quartzite a little downstream from the bridge shows current-bedding, almost certainly right-way-up, as might be expected.

(b) Banded Leven Schists are very poorly exposed between the foot-bridge and the new road, but sufficiently to justify the assumption that they form part of a continuous outcrop reaching north through the ragged plantation west of Clachaig. The dip is S.W. at 35°.

(c) The cutting exposure on the new road showing calc-silicate-hornfels is excellent. Only a few of its beds retain mica dating from the regional metamorphism. The dip is westerly at 45°, with contortions. South of the road this calc-silicate outcrop can be followed for 300 yards south of east until cut off by the An t-Sròn " Granite ". North of the road it crosses the Coe at a gorge to join the Signal Hill exposures leading north-westwards past Leacantuim to Bridge of Coe. Signal Hill is shown by a triangle in Fig. 10.

The gorge just mentioned has other interests. Its eastern beginning is eroded in a large porphyrite dyke, already mentioned in the plantation west of Clachaig. Its greater part, however, follows for a quarter of a mile an east-north-east dyke of hornblende-lamprophyre, sometimes 10 feet thick. A specimen collected by Peach is so coarsely crystalline that it might be classed with the appinites (S 11612). In fact, before the name appinite was introduced it had been suggested to call the rocks concerned clachaigite on the strength of this specimen. Detailed examination is difficult unless the Coe is exceptionally low. It has, however, been found that the dyke is often a normal hornblende-lamprophyre, sometimes veined and sometimes cut to pieces by aplite (S 39702-5), presumably cognate. The reaction phenomena are as might be expected.

(d) On emerging from the cutting in calc-silicate-hornfels the road runs west on a low parapet ; but to the north, especially along the continuation of the Coe gorge (here spanned by a tourist foot-bridge leading to Signal Hill), there are excellent exposures of typical unbanded Leven Schist, somewhat garnetiferous (S 39690). To begin with, the schist is clearly affected by contact-alteration ; but its garnets undoubtedly belong to the regional metamorphism of the district. Other good exposures with garnets easy to see occur where the road crosses Allt na Muidhe and in a cutting near Achnacon farm (S 39689).

By the time it has reached Achnacon this Leven Schist outcrop (d) is seen to separate the Signal Hill—Leacantuim band (c) of Ballachulish Limestone from its fellow (e). The latter is of identical stratigraphical material, but is mounted at a higher level on the structural ladder, so that from the slopes of Meall Mòr it overlooks the farm. Admittedly the north-westerly continuation past Achnacon of the Leven Schists in the (d) position is largely obscured by valley-bottom alluvium ; but there is a small typical exposure beside a rough track, 250 yards N. of the farm. It lies 150 yards N.E. of the new road, along which for a space no solid rock is found.

(e) The great tongue of calcareous schist (Ballachulish Limestone) outcropping along the south-eastern slopes of Meall Mòr can readily be appreciated in the view ; but N.W. of Achnacon, for 800 yards, no rocks are seen at the roadside. Then at frequent intervals until Loch Leven is reached there are numerous rather poor exposures of greatly contorted impure calcareous schist. The most interesting of these lies almost due W. of Leacantuim farm which stands on the other side of the river. Here in a stream that passes under the new road, and also in the bank of the road, Maufe found the impure calcareous schist to contain a band or bands of white limestone such as is commonly seen elsewhere at unbroken contacts of Ballachulish Limestone and Leven Schist. It is therefore probable that the Leven Schist outcrop (d) extends under alluvium very nearly to this spot. There is no chance of a further extension, except as a very narrow band, for nearby the Coe gives exposures referable to the Leacantuim belt (c). Approximately, therefore, the Meall Mòr (e) and Leacantuim (c) outcrops of Ballachulish Limestone unite east of Leacantuim.

To avoid breaking the continuity of theme, no mention was made when we passed Allt na Muidhe and Achnacon of three important *geological views* well seen from these localities. The first centres on a cap of Glen Coe Quartzite resting on Leven Schist in Beinn Maol Chaluim beyond the head of Fionn Ghleann, 3 miles S.S.E. of Achnacon (p. 87). The second is focussed on a craggy summit ridge called Aonach Dubh a' Ghlinne (Black Ridge of the Glen) composed of Leven Schists baked by the An t-Sròn " Granite " on the west side of Fionn Ghleann, one mile S. by E. of Achnacon. The third is of glacial interest and concerns deposits near the junction of the river of Fionn Ghleann with Allt na Muidhe, half a mile south of Achnacon. For half a mile upstream from the junction, the bottom of Fionn Ghleann displays three remarkably fine fluvioglacial fans, developed preferentially on the south-west of the stream ; while the combined river is paralleled, this time on its east side, by an uncommonly continuous morainic ridge carrying a footpath which joins the road near a sheepfold. The detailed position of the various ice-fronts involved has not yet been worked out.

In addition to these more or less localised views, the new road affords an excellent chance of following in the scenery the various outcrops that accompany the old road together with the backing of Glen Coe Quartzite in the ridge connecting the Pap with Sgòrr nam Fiannaidh. Also, looking north-west across Loch Leven, one can easily pick out the rounded summit of Tom Meadhoin. Here, it will be remembered, the Glen Coe Quartzite rises antiformally from under Leven Schist (Fig. 9, p. 51) in marked contrast with its cap-relationship in Beinn Maol Chaluim.

Meall Dearg.—The Meall Dearg outcrop of the Ballachulish Core and Slide is illustrated in Fig. 23, p. 156. The core, consisting of calc-silicate-hornfels, is seen as a strip north of a felsite dyke that is earlier than the porphyrite Fault-Intrusion making Meall Dearg. Undoubted " cover " Leven Schists are exposed to the south just across this dyke (lettered PH. for phyllite).

The geology north of the calc-silicate strip is very confused by outcrops of Fault-Intrusion, all of which are not strictly synchronous. Exposures are sometimes poor. There is, however, practically no doubt but that the calc-silicate lies on the downthrow side of a branch of the main fault bounding the Glen Coe Cauldron-Subsidence. It also seems to be sharply downfolded by secondary folding earlier than this subsidence. Exposures east of the Meall Dearg ridge show what is interpreted as banded Leven Schists (phyllites) followed by Glen Coe Quartzite. The short outcrop of Ballachulish Limestone indicated in Fig. 23 north of the banded Leven Schists has been drawn through ground covered by glacial drift.

Coire Mhorair.—Metamorphic sediments emerge in Coire Mhorair from below uptilted Devonian lavas within the Cauldron-Subsidence of Glen Coe, and exposures are all that could be desired (Fig. 24). Dips throughout are very steep, and the strike is roughly east and west. The succession of outcrops from south to north is as follows : (*a*) Devonian lavas ; (*b*) thin Devonian shales ; (*c*) *unconformity* ; (*d*) thick, pale grey, very micaceous limestone, not contact-altered, belonging to the middle part of the Ballachulish Limestone (6) ; (*e*) *Sgòrr a' Choise Slide*—S.A.C.S. ; (*f*) black Ballachulish Slates (5) (as schists) along with striped zone of Appin Quartzite (4), together 60 feet thick ; (*g*) *Ballachulish Slide*—B.S. ; (*h*) crags of Glen Coe (or older) Quartzite (8, 10 or 12 of chap. vii) ; (*i*) *southern branch of Boundary-Fault of Cauldron-Subsidence*, succeeded by porphyrite as Fault-Intrusion.

The striped Appin Quartzite, grouped with the black slates, or schist, in Fig. 24, can be seen gradually creeping across successive bedding planes of the Glen Coe (or older) Quartzite, clearly marking the course of the Ballachulish Slide. The locality can be recommended to all who wish to walk for a considerable distance along a bare, obviously transgressive, major slide. A party may well visit it in conjunction with neighbouring exposures of the Boundary-Fault of the Cauldron-Subsidence (p. 158). The Ballachulish Slates are really schists, much more metamorphic, for instance, than the Leven Schists at Loch Achtriochtan, and carry garnet (S 12924).

The quartzite listed as (*h*) north of the Ballachulish Slide (*g*) is shown as Glen Coe Quartzite in Section BB of Sheet 53, but is more guardedly called Glen Coe or older in the account just given. Caution is required, for there are three fine-grained quartzites in the Loch Leven succession, namely Glen Coe (8), Binnein (10) and Eilde (12), that cannot be safely distinguished in isolated exposures. It is natural to think of the Coire Mhorair outcrop as belonging to the Glen Coe Quartzite if one approaches from the west, where the Ballachulish Slide is almost always separated from the Glen Coe Quartzite by a layer of banded Leven Schists ; but when presently we consider the district from Altnafeadh to Coire an Easain we find that other possibilities must be admitted.

Immediately east of Coire Mhorair lies Coire Odhar-mhòr, from which two streams drain northward (Fig. 24). Here we find quartzite occupying the whole space between two branches of the Boundary-Fault of the Cauldron-Subsidence. It may be the same quartzite as in Coire Mhorair. At any rate it is certainly of Glen Coe, Binnein or Eilde age. The Coire Odhar-mhòr quartzite dips steeply more or less south-west. Beyond to the north the country-rock consists of quartzo-felspathic micaceous flags (Eilde Flags, 13, of chap. vii), with a band of quartzite—infolded or interstratified, we do not know.

This broken succession of outcrops brings home to us very vividly that the Ballachulish Limestone of Coire Mhorair, within the Cauldron-Subsidence, structurally overlies the Eilde Flags exposed outside in Coire Odhar-mhòr. Turn now to one-inch Sheet 53, and our view expands. Clearly the Ballachulish Limestone from the mouth of Glen Coe all the way to Coire Mhorair overlies the quartzite, mica-schist, flag assemblage that crosses Loch Leven and River Leven from the mouth of the Coe to at least two miles upstream from Kinlochleven.

Also it is clear that the quartzite or quartzites of Coire Mhorair and Coire Odhar-mhòr intervene structurally between the Ballachulish Limestone of Coire Mhorair and the Eilde Flags of Coire Odhar-mhòr.

H. Altnafeadh South-East by Càm Ghleann to Coire an Easain

Proceeding east for half a mile from the outcrop of Ballachulish Limestone at Coire Mhorair, and keeping south of the southern branch of the Boundary-Fault of the Glen Coe Cauldron-Subsidence, one crosses the Devonian volcanics of Fig. 19, eventually reaching their margin. Unfortunately on the summit ridge this is hidden under drift ; but down the slope, a mile east-south-east of the Coire Mhorair limestone, Devonian sediments underlying agglomerate are seen resting unconformably on Eilde Flags—micaceous quartzo-felspathic flags of psammitic " Moine " type (13 of chap. vii. *Cf.* Barrow 1904).

From this point sufficient exposures show that Eilde Flags emerge from under the Devonian volcanic pile all the way downhill to the Glen Coe road ; and that, apart from igneous interruptions, these flags extend along the latter past Altnafeadh until the volcanics meet the Boundary-Fault of the Cauldron-Subsidence. The strike of the flags is south-east, roughly parallel with that of the quartzite of Coire Odhar-mhòr ; and dips are steep, perhaps more often south-west than north-east.

Within the flag area, just outlined north of the road, there is an important quartzite outcrop at Stob Mhic Mhartuin (2300 ft, Figs. 19, 26). Its beds also strike south-east and stand about vertical. Downhill this quartzite is lost sight of under drift ; and as it does not reappear in exposures nearer the road it is mapped in Sheet 53, diagrammatically, as folded out.

Across the road the Eilde Flag belt can be traced by exposures in stream courses to about a mile beyond Càm Ghleann, always with south-east strike and steep dips (Fig. 29). The Ballachulish Limestone and associated quartzite of Coire Mhorair must lie on the south-west side of this belt, though the limestone for half a dozen miles is hidden by the Devonian lavas. In keeping with this, fine-grained quartzite with south-east strike emerges from beneath the lavas at the foot of Stob Dearg and continues for two miles south-eastwards to Glen Etive.

The maximum cross-strike width of the steep Stob Dearg quartzite is 400 yards ; that of the Coire Odhar-mhòr quartzite is 300 yards ; and that of lava-covered space through which the Coire Mhorair quartzite can be expected to run to separate the Coire Mhorair limestone, seen to the west, from the Eilde Flags, seen to the east, is also 300 yards. It follows that the Stob Dearg, Coire Odhar-mhòr and Coire Mhorair quartzites appear to be identical. They all belong to the Glen Coe—or older—category. The direct association with Eilde Flags (13) at Stob Dearg suggests that all of them are Eilde Quartzite (12). In this case the Ballachulish Slide at Coire Mhorair has cut out everything between the striped zone of the Appin Quartzite (4) and the Eilde Quartzite (12). This, however, is not established. E. B. B.

The Stob Dearg outcrop of quartzite disappears under Devonian lavas in Glen Etive in the north-west corner of Fig. 29. When, much diminished, it reappears two miles further south it soon turns to run south-westwards across the burn that drains Coire an Easain. Here the stream section maps south-eastwards as follows :

Devonian agglomerate (called breccia in Fig. 29)
Unconformity
Thick hornfelsed garnetiferous mica-schist (Leven Schist, 7, cover of Ballachulish Core)
Thin calc-silicate-hornfels (Ballachulish Limestone, 6, of Ballachulish Core)
Ballachulish Slide (only indicated by a note in Fig. 29)
Thin quartzite (reappearance of Stob Dearg outcrop of Glen Coe, or older, Quartzite)
Eilde Flags (13)
North-west branch of Boundary-Fault of Cauldron-Subsidence (heavy line, Fig. 29)
Narrow Early Fault-Intrusion
Eilde Flags (13)
South-east branch of Boundary-Fault (heavy line, Fig. 29)
Broad Main Fault-Intrusion
Eilde Flags, very extensive along River Bà

The general dip is westerly so that the Leven Schists appear on local evidence to be the highest schist member here exposed within the Cauldron-Subsidence ; and this appearance is emphasised by the great spread of Eilde Flags outside the subsidence. Mica-schist shown in Fig. 29 at the south end of the Moor of Rannoch Pluton, although of similar character to the mica-schist listed above, clearly belongs to the Reservoir outcrop (p. 108) which, further north, emerges from below Stob Quartzite and Eilde Flags. C. T. C., E. B. B.

If instead of taking a local view we look back to Coire Mhorair and Glen Coe, we get the same answer. We are certainly dealing with Ballachulish Limestone in one and the same structural position all along the line, though connecting links are hidden under Devonian lavas. We have already realised that from the mouth of the Coe to Coire Mhorair this layer of limestone overlies the assemblage of quartzite and mica-schist that outcrops to the north. It follows of necessity that from Coire Mhorair to Coire an Easain the limestone overlies the predominantly flag assemblage that outcrops to north-east and (at Coire an Easain) to south-east.

In keeping with this, six miles to the south-east, what is taken to be Ballachulish Limestone with the same tectonic setting has been described as outcropping at a low angle well up in the escarpment of Beinn Doirean (Bailey and Macgregor 1912, pl. x, where the scale should have been drawn ½ inch to 1 mile). Similarly, eighteen miles to the north-east in the Ben Alder country beyond Loch Ossian, Carruthers has shown that the well known Loch Laggan Limestone is disposed in a synform overlooking Moine surroundings. He does not call this limestone Ballachulish Limestone, but he does say that it and its immediate associates seem " to represent a reappearance of some members of the Lochaber Series," which amounts practically to the same thing (1923, p. 34). J. G. C. Anderson has recently continued the mapping of this limestone, and has published a very valuable map extending north-east to the Monadhliath Mountains. Readers are recommended to study his paper very carefully (1956).

Returning to Sheet 53 we may note that Coire an Easain lies six miles south-east of Coire Mhorair, but only four miles east of the Windows of Etive, whither we now go.

I. Glen Coe to Glen Creran and Glen Etive

Introduction.—Our present district is roughly triangular in shape, and mostly falls within the drainage basin of Glen Creran. Its north-westerly portion is limited by a complicated outcrop of Ballachulish Limestone (described under the Ballachulish and Glen Coe headings, E, G), which reaches from Glen Coe to Glen Creran and Glen Ure ; while its eastern angle is bounded by the Cauldron-Subsidence of Glen Coe and the Cruachan Pluton, these two meeting in Glen Etive.

In previous pages we have defined the core of the recumbent Ballachulish Syncline as the part which consists of Ballachulish Limestone and younger formations. We have then traced the outcrop of this core, and found that it constitutes a polygonal ring which, in spite of being breached by the Cruachan Pluton, in large measure surrounds our district. Commencing in the south-west at the margin of the pluton, the following localities may be recalled as markers : Glen Ure and Loch Creran (Pl. IV, reaching S. of Sheet 53), Gleann an Fhiodh (Pl. III), Bridge of Coe and Loch Achtriochtan (Fig. 10), Coire Mhorair (Fig. 24), Coire an Easain (Fig. 29, E. margin of Sheet 53).

In our accounts we have continually emphasised that this ring-outcrop has two contrasted sides. The formations outcropping outside the ring serve as a foundation to the core in a big sense, that is they underlie it if we disregard steep secondary inversions ; while the formations (in large measure stratigraphically identical) that outcrop inside the ring function as a cover to the core similarly interpreted. The reader is referred to discussions already given in connection with Stob Bàn (p. 47), Glen Creran (p. 64), Coire Mhorair (p. 81) and Coire an Easain (p. 82).

There is only one fairly large-scale complication in this connection, and it is due to the Ballachulish Core in Glen Coe locally dividing into a lower and an upper portion, in the (*c*) and (*e*) positions of p. 78.

The Leven Schist cover just referred to is responsible for much the greater part of the surface of our present district stretching from Glen Coe to Glen Creran and Glen Etive. After describing it in some detail, we shall take the following subjects in order : the Windows of Etive, opened by erosion in this wide-spread cover ; caps of Glen Coe Quartzite, locally surmounting the same ;

and a problematical quartzite at Beinn Ceitlein, outcropping in the angle between two branches of the Boundary-Fault of the Glen Coe Cauldron and cut across by an offshoot of the Cruachan Pluton, where this advances northward into the sunken area.

Since the Ballachulish Limestone round the Glen Creran area seems everywhere to make essentially unbroken contact with the Leven Schist cover, and since current-bedding elsewhere in both Appin and Glen Coe Quartzites proves Ballachulish Limestone to be younger than Leven Schists, the district affords a splendid example of large-scale inversion. This inversion, however, does not affect the Glen Coe Quartzite of the caps, so far at least as they have been examined for current-bedding. The quartzite here is right-way-up and is separated by slides from the Leven Schists below, Nor, of course, does the Glen Creran Inversion affect the Glen Coe Quartzite exposed below the Ballachulish Slide in the Windows of Etive. E. B. B.

Leven Schist Cover.—The Leven Schist cover in the heart of the great pitch-depression of Glen Creran shows a certain amount of variety from point to point ; but it has not been found possible to subdivide it into groups, and such local differences as do occur are largely effects of metamorphism. The prevailing type is a homogeneous greenish-grey quartzose mica-schist, with alternating layers of somewhat more and somewhat less sandy nature. Bright little flakes or porphyroblasts of biotite are highly characteristic, just as in the eastern part of the type outcrop of Leven Schists at the mouth of Loch Leven north of Ballachulish Ferry. Anyone wishing to confirm this comparison should visit the cover Leven Schists as exposed in Allt Socaich (Pl. III). Not only are the schists themselves identical in character with those of the type area, but also the adjoining portion of the Ballachulish Limestone is exactly like that seen in corresponding position in the hill-top crag above North Ballachulish (p. 39).

Additional minerals are found in the eastern part of the district. Small blades of actinolite occur up Allt na Muidhe, and towards Glen Etive large crystals of the same mineral are frequently encountered. Garnets also are found in Allt na Muidhe all the way to Glen Coe, particularly along the edges of quartzose bands. In the district south of the An t-Sròn Pluton and east of Beinn Fhionnlaidh garnets come to be so abundant that much of the deposit assumes the character of a garnetiferous mica-schist.

Contact-alteration is very marked in the neighbourhood of the An t-Sròn Pluton, and on the west side of Fionn Ghleann the baked mica-schists stand out as a craggy ridge well seen from Glen Coe. The development of actinolites and garnets is in no way connected with this contact-metamorphism. It belongs to the earlier, regional metamorphism of the district. H. B. M.

The garnetiferous mica-schist is also strongly hornfelsed in the neighbourhood of the Cruachan Pluton. On the slopes of Beinn Ceitlein, south-east of Glen Etive, the garnets are usually surrounded by dark rims, partly composed of biotite, and elongated in a definite direction, showing that the rock has been considerably sheared since the garnets were developed. This confirms distributional and microscopic evidence that the garnets are pre-pluton, for the rocks of the pluton are very rarely sheared. On the same north-western slope of Beinn Ceitlein the garnetiferous mica-schist sometimes includes thin seams containing dark green actinolite, occasionally arranged in radiate forms, in a matrix of mica-schist with abundant flakes of mica. C. T. C.

Windows of Etive.—The great layer of Leven Schists just described is two or three thousand feet thick, and out of it a whole series of hills and valleys has been carved. In Glen Etive and its tributaries, Gleann Fhaolain and Gleann Chàrnan, erosion has cut sufficiently deep to lay bare the foundation upon which the Leven Schists rest (Fig. 7, G, H ; Section BB, Sheet 53). The openings thus pierced by erosion have come to be known as the Windows of Etive, and in them the following sequence of rocks is revealed in descending order beneath the great covering of garnetiferous mica-schist :

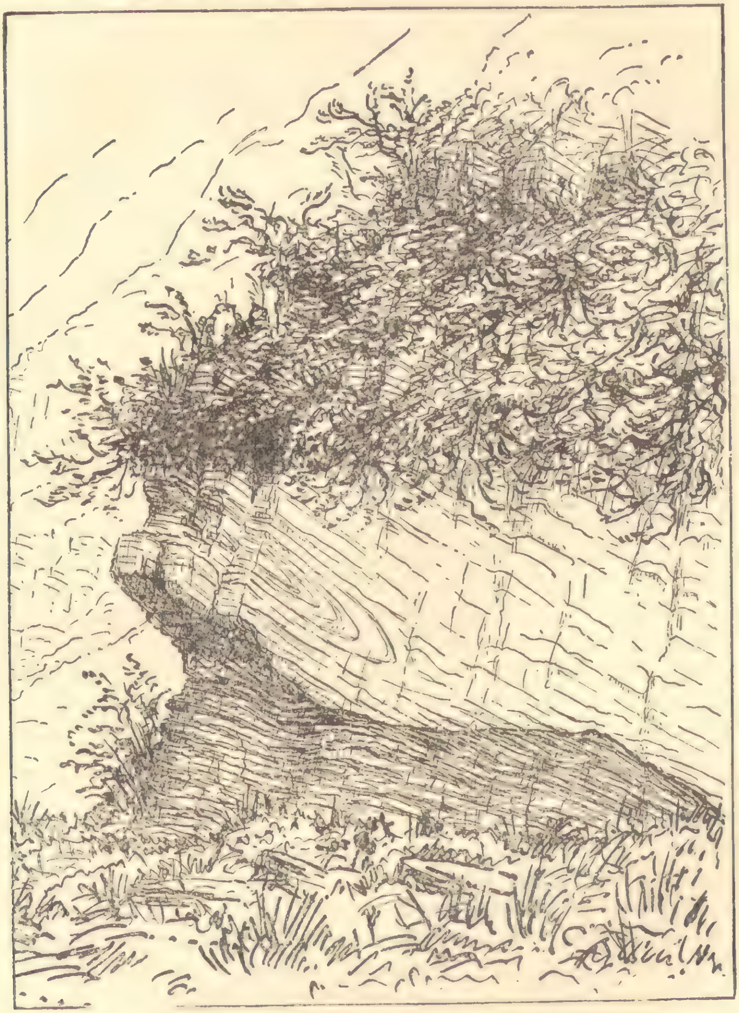


FIG. 11. Sketch of Ballachulish Slide on S.W. side of Gleann Chàrnan

Calc-silicate-hornfels (Ballachulish Limestone) lying discordantly, through the intervention of the Ballachulish Slide, upon banded Leven Schists

	Thickness in feet
Calc-silicate-hornfels (Ballachulish Limestone)	15—100
Ballachulish Slide (heavy line on Sheet 53)	—
Banded margin of Leven Schists	0—100
Fine-grained Glen Coe Quartzite	—

The smaller measurements are from Beinn Ceitlein east of Glen Etive. The calc-silicate-hornfels (south of Dalness, S 11485-6 ; Allt Fhaolain, S 11625) is a fine-grained greenish-white rock in which little prisms of tremolite can often be recognised. The other important constituents are granular diopside (malacolite) and felspar. Calcite is rare. The banded Levens are an alternating series of mica-schist and quartzite. In keeping, the top of the underlying Glen Coe Quartzite is finely banded with mica-schist. C. T. C., H. B. M.

For the most part the bedding of the quartzite, as exposed in Gleann Fhaolain, west of Dalness, is straight, but two instances of uninverted current-bedding have been noted. This was in accordance with expectation. E. B. B.

The Ballachulish Slide was recognised in the Windows as a result of the interpretation of the Callert district north of Loch Leven (p. 50). Upon revisiting the Gleann Chàrnan exposures it was found that the calc-silicate-hornfels is separated by a discernible plane of discordance from the underlying banded Leven Schists (Fig. 11). This plane is less marked by any appearance of disruption than the well known thrust-planes of the North-West Highlands. It only occasionally transgresses the bedding and foliation of the schists above and below. Sometimes, in addition to such transgressions, one finds small, flat, isoclinal folds affecting the schists above or below without involving the plane itself. In other cases, however, the plane seems to be folded along with the schists it separates.
C. T. C., E. B. B.

It is instructive to compare the Window succession, revealed by erosion in the heart of the great Glen Creran Pitch-Depression, with the rim successions that have already been described. One is struck at once with the practical identity of the Etive sections with those exposed 2½ miles to the north by the roadside west of Clachaig Hotel, Glen Coe (p. 75), and again 4 miles to the west-south-west in Glen Ure (p. 64). The only noteworthy difference is that the calc-silicate-hornfels of the Windows is a good deal thinner. The thinning of the calc-silicate is particularly marked in the most easterly Window exposures, on Beinn Ceitlein ; and this, along with concomitant reduction of underlying banded Levens, strongly recalls what is seen at Coire an Easain that lies another 6 miles to the east (p. 82). There is, however, a much stronger development everywhere in Glen Etive of underlying quartzite than at Coire an Easain.

The Windows of Etive can be sampled cross-country from Glen Coe starting from Achnacon farm (Fig. 10). The route lies up Fionn Ghleann and crosses Bealach Fhionnghaill into Gleann Chàrnan. On the way Fionn Ghleann affords interesting exposures of the An t-Sròn outcrop of Fault-Intrusion ; but to do justice to the Windows it is necessary to begin in Glen Etive, which is served by a second-class road. C. T. C., H. B. M., E. B. B.

Caps of Glen Coe Quartzite.—The common practice in this memoir is to relegate history of research to chapter ii, but in the present case it seems desirable to present the facts rather fully in their proper context as they were successively appreciated. In the *Summary of Progress* for 1904 Clough gave the first description of the schist succession exposed in the Windows of Etive (1905, p. 65). His account deals with what is seen east of a north-to-south tongue of Fault-Intrusion on the south-east side of the glen, opposite Dalness. It includes a reference to quartzite that reaches up to the summit of Beinn Ceitlein. This is the problematical quartzite to be described presently, and Clough pointed out, quite correctly, that it is separated from the Window exposure by a fault. No mention is made of an obvious cap of quartzite on neighbouring Stob Dubh, because it lay beyond the area actually mapped.

Next year Clough could not continue field work in the Highlands, and Maufe completed the mapping of the Windows, both sides of Glen Etive. In the course of his work he mapped not only the Stob Dubh cap (2897 ft), but also another (2967 ft) on the Beinn Maol Chaluim ridge (Section BB, Sheet 53). Caps on Beinn Fhionnlaidh (3139 ft) further west had already been mapped with some little confusion by Kynaston before Maufe's advent, and did not for the time being enter into the story.

Maufe's reaction is expressed in the *Summary of Progress* for 1905 as follows: "The structure of the district is evidently that of a huge overfold, the limbs of which dip gently westwards and are at least three miles in length (from trough to crest). The quartzite which caps the hills also forms the floors of the glens" (1906, p. 91). This is the first announcement of what later has come to be called the Recumbent Fold, or Recumbent Syncline, of Ballachulish.

Much has happened since 1905, when the stratigraphical succession of the district was very imperfectly known, and when complications due to slides were not suspected; but the fact remains that Maufe was justified in claiming that the quartzites above and below the great Glen Etive mica-schist are stratigraphically one and the same, and that they owe their relative position to large-scale tectonics. Maufe quite properly assumed that the mica-schist had only two stratigraphical sides. One of these, he said, was bounded by the great complex of limestone, black slate and gritty quartzite, at the time only partially understood, which outcrops between Ballachulish and Glen Creran. Therefore the mica-schist is not interbedded between two different fine-grained quartzites. In other words the summit and valley-floor quartzites of Glen Etive are stratigraphically identical.

In 1905 Maufe naturally thought that the axial plane of his recumbent fold lay in the middle of the 3000-ft mica-schist. The band of calc-silicate-hornfels, occurring a little above the lower quartzite, was interpreted as a local impersistent intercalation, and was looked for (in vain) a little below the upper quartzite. Its recognition as Ballachulish Limestone core resting on Ballachulish Slide had to await the interpretation of the Callert district north of Loch Leven (Bailey 1909, p. 51).

A further complication later followed the realisation that current-bedding can often distinguish between right-way-up and upside-down. In 1930 Beinn Maol Chaluim was revisited, and in 1932 Beinn Fhionnlaidh was remapped (Bailey 1934a, p. 504). In both cases the quartzite was confirmed as of Glen Coe type; but in both cases, contrary to expectation, it was found to be uninverted.

The Beinn Maol Chaluim cap of quartzite has a normal dip of about 50°, while the plane separating it from underlying Leven Schist is much more gently inclined. This plane therefore is an obvious slide.

The Beinn Fhionnlaidh quartzite has two outcrops. In both there is a more or less eastern margin which acts on the whole as base, and a more or less western margin which acts on the whole as top. There is a great deal of small-scale folding, and the top of the western outcrop is packed into isoclines with steep westward inclination. Current-bedding at a number of places shows that in both outcrops the quartzite is interbedded between an older mica-schist below and a younger mica-schist above. The interpretation offered on Sheet 53 is that the older mica-schist is on the Binnein horizon of chapter vii, while the younger mica-schist is Leven Schist. The Cruachan Pluton has greatly altered the mica-schists, and there seems no chance of distinguishing between Binnein and Leven horizons on the score of lithology. It appears certain, however, that the older mica-schist must be separated from the Leven Schists of the main underlying spread by slides (Fig. 7, H, p. 48).

The quartzite cap of Stob Dubh has not been revisited in search of current-bedding, so that we do not know whether or no it is inverted. Maufe mapped it as resting on a zone of banded mica-schist and quartzite, which suggests a normal passage to the underlying Leven Schists—but the same appearance is furnished at Beinn Fhionnlaidh where, as we have seen, the quartzite is uninverted.

E. B. B.

Problematical Quartzite of Beinn Ceitlein.—The upper part of Beinn Ceitlein, facing Dalness from the east side of Glen Etive, is composed of a very considerable outcrop of Glen Coe Quartzite. From north to south this measures two miles, and from east to west three-quarters of a mile. Its boundaries are as follows: to the south, an arcuate dyke of acid granite named after Meall Odhar—this is a post-Cruachan member of the great Etive plutonic complex ; to the east, an important offshoot of the Cruachan member of the same complex, which here penetrates the Cauldron-Subsidence of Glen Coe ; to the north, the main branch of the Boundary-Fault of the Cauldron-Subsidence, introducing rhyolite lavas ; and, to the west, another branch of the Boundary-Fault. This western branch has a general north-westerly or westerly inclination of about 50°, and may conveniently be called the Beinn Ceitlein Fault.

The strike of the quartzite within the above limits is northerly with a tendency to swing to north-west in the north. The dip is westerly at angles of from 30° to 50°. This attitude contrasts with that of the Window succession seen across the Beinn Ceitlein Fault on slopes leading down to the River Etive and up to the summit of Stob Dubh. Here dips are usually gentler, 10° to 30°, and are commonly directed south-west.

It is almost certain that the Beinn Ceitlein quartzite corresponds with the valley-bottom outcrops of Glen Coe Quartzite exposed to the west in Glen Etive, Gleann Fhaolain and Gleann Chàrnan. The evidence is supplied by a very restricted outcrop of fine-grained green tremolitic schist or calc-silicate-hornfels (S 11449) found in close association with the quartzite. This tremolitic rock agrees in character with (S 11486, 11625), calc-silicate-hornfelses framing the Windows of Etive, close at hand, and with (S 15439, 15440) of the same stratigraphical horizon in Glen Nevis. It is shown on Sheet 53 as a minute dot of blue, with national grid reference 182500, at the north-east end of the summit ridge of Beinn Ceitlein. Useful landmarks to help in its location are provided by a small lochan to the south and rhyolite lavas within the main Cauldron to the north. The distance from lochan to lavas is about 80 yards, and the green schist passes midway between as a narrow strip traceable W.N.W. for 100 yards. It is overlain by a sheet of fine-grained lamprophyre (S 11448), while to the north it is cut off by an extremely inconspicuous fault, probably of much the same age as the main Boundary-Fault. On the south, it seems steeply to overlie a thin set of semipelitic beds alternating with quartzite. These may well represent the banded Leven Schists below the Ballachulish Slide of the Window succession.

It was thought in early days that the Beinn Ceitlein Fault probably threw down to the east, because northwards it converges on the main branch of the Boundary-Fault of the Cauldron, which here unmistakably throws down to the north-east. In fact, before the significance of the associated patch of green schist was realised, the Beinn Ceitlein quartzite was referred to the cap, rather than the valley-bottom, position of Glen Coe Quartzite in the Window succession. In other words, the Beinn Ceitlein quartzite was supposed to be a down-faulted continuation of the Stob Dubh band (Clough, Maufe and Bailey 1909, p. 628 and fig. 2, p. 627). This last item of interpretation was afterwards abandoned ; but in the first edition of the present memoir it was pointed out that since the Beinn Ceitlein quartzite and fault have roughly the same inclination, it is still possible to suppose that the fault may throw down to the east in spite of valley-bottom quartzite rising to outcrop in that direction.

Here it may be pointed out that if the Beinn Ceitlein Fault throws down to the east it is a reversed fault of rather low inclination. This, however, does not present any special difficulty, for the Boundary-Fault of the Cauldron-Subsidence has reversed inclination all along the northern and north-eastern sectors of its course.

C. T. C.

When the first edition of this memoir was prepared, the writer thought with Clough that the Beinn Ceitlein Fault threw down to the east. Now, however, he thinks it much more probable that it throws down to the west, and that it is a normal fault merging into a broken monocline. According to this view, the Beinn Ceitlein Fault is likely to be the curved continuation of the outer branch of the Boundary-Fault which, after interruption by the Cruachan Pluton, reappears along Gleann Chàrnan (*cf.* Figs. 17, 18).

The downthrow side of the Beinn Ceitlein Fault may perhaps some day be identified more certainly by reference to accompanying Fault-Intrusion. According to experience branches of the Glen Coe Boundary-Fault lie on the downthrow side of associated Fault-Intrusion. Clough has evidently found it very difficult to decipher the local evidence, for in some places he maps the fault as occurring on the one side of the intrusion, and in other places on the other side. It is quite possible that the relationship is not regular, since here two branches of the Boundary-Fault meet and each has a Fault-Intrusion accompaniment.

E. B. B.

Dalness.—The presence of quartzite caps on Beinn Maol Chaluim and Stob Dubh, a little outside the main Boundary-Fault of the Glen Coe cauldron, renders it practically certain that the same quartzite, faulted down, is locally preserved under the lavas of the Dalness district. A few minute quartzite inliers are described later as jutting up irregularly through andesite lavas in the Glen Etive hollow. They all fall within a mile east, and half a mile north-east, of Dalness (p. 149).

C. T. C.

CHAPTER VII

METAMORPHIC ROCKS
KINLOCHLEVEN RECUMBENT ANTICLINE

J. GLEN COE AND THE DEVIL'S STAIRCASE NORTH TO STOB COIRE EASAIN

Introduction.—The southern boundary of the district to be considered runs roughly up Glen Coe to Loch Achtriochtan, and then follows the edge of the Cauldron-Subsidence of Glen Coe to a little past the Devil's Staircase. The eastern boundary coincides with the eastern limit of the Eilde Flag outcrop between the Devil's Staircase and Loch-Eilde Beag ; and beyond this is furnished by the eastern margin of Sheet 53 (Geol.). The north-western boundary is determined approximately by the north-western limit of the Glen Coe Quartzite outcrop from Mam na Gualainn, overlooking Loch Leven, to the north-east corner of Sheet 53, where stands Stob Coire Easain (3545 ft), one of two mountains bearing this name. As always, there is a certain laxity of definition, for reference will be made to bordering Leven Schists and also to the isolated outcrop of Glen Coe Quartzite at Tom Meadhoin west of Mam na Gualainn.

In this extensive area the following stratigraphical succession has been established—the numbers accord with the convention adopted in previous chapters :

(7) Leven Schists (*youngest*)
(8) Glen Coe Quartzite
(9) Binnein Schists
(10) Binnein Quartzite
(11) Eilde Schists
(12) Eilde Quartzite
(13) Eilde Flags (*oldest*)

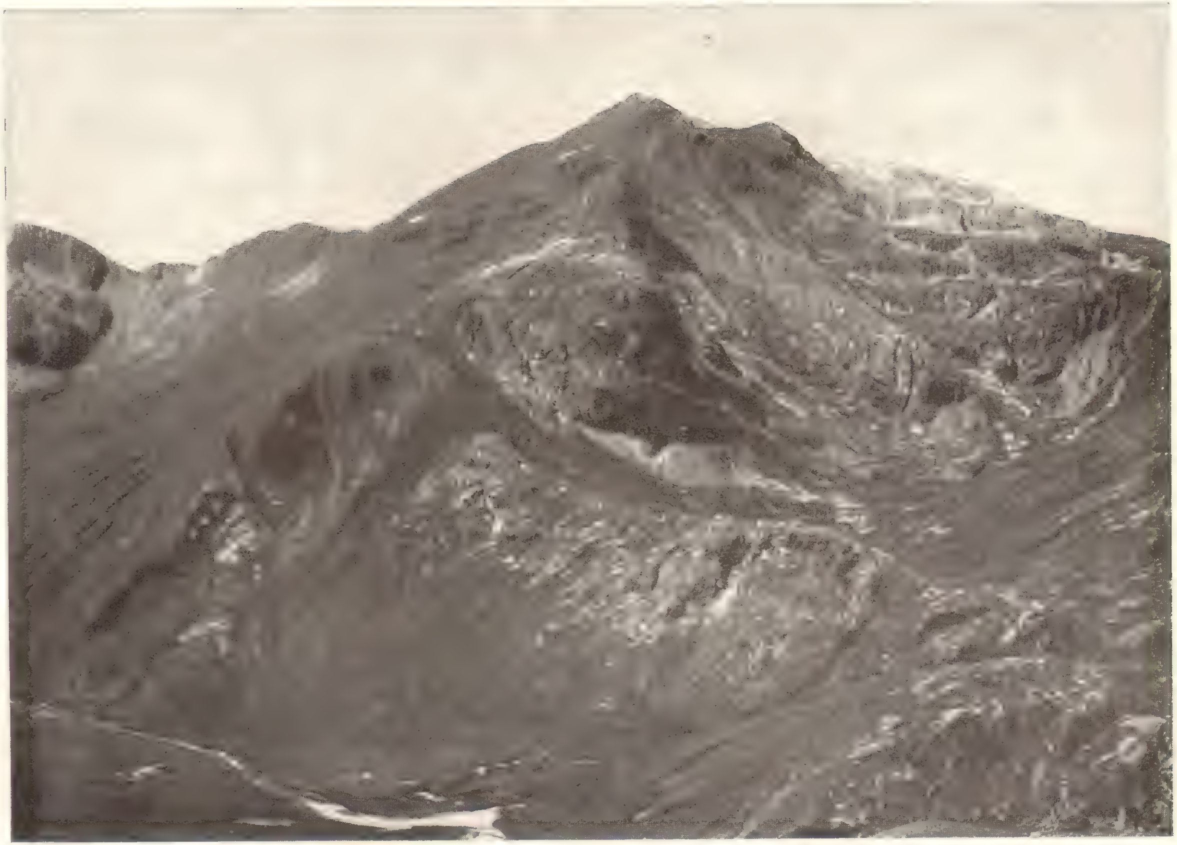
The name-localities with their national grid references are : Loch Leven 090595 ; Pap of Glen Coe 125595 ; Binnein Mòr 213663 ; Loch-Eilde Mòr 230638 ; Sgùrr Eilde Mòr 232654 (Fig. 12).

It has already been explained in chapter ii how this succession was first established on lithological grounds by R. G. Carruthers, and how later it was confirmed through attention to current-bedding by T. Vogt, S. Buckstaff, O. N. Rove, T. L. Tanton and others. Briefly, so far as Lochlevenside is concerned, the lithological argument is as follows, in two main steps :

(1) The pale, greenish-grey, spangled Leven Schists cannot be correlated with the dark, grey, non-spangled Binnein Schists ; thus the Glen Coe Quartzite has two stratigraphical partners, neither of which corresponds with the Eilde Flags ; therefore the Glen Coe Quartzite must be distinct from the Eilde Quartzite (though both are felspathic and closely similar).

(2) The Binnein Quartzite is purer than the Glen Coe and Eilde Quartzites and must therefore be a distinct horizon ; accordingly there are three quartzites in the succession, and the Binnein Schists, separating Glen Coe Quartzite from Binnein Quartzite, must be different from the Eilde Schists, separating Binnein Quartzite from Eilde Quartzite (though Binnein Schists and Eilde Schists are closely similar).

As for current-bedding, which is wonderfully preserved in spite of structural complexities, the argument is as follows : Glen Coe Quartzite is seen to be older than Leven Schists and younger than Binnein Schists ; Binnein Quartzite is seen to be older than Binnein Schists and younger than Eilde Schists ; Eilde Quartzite is seen to be older than Eilde Schists and is followed by Eilde Flags. The readings



Sgùrr a’ Mhàim across Allt Coire a’ Mhail
Folded Glen Coe Quartzite

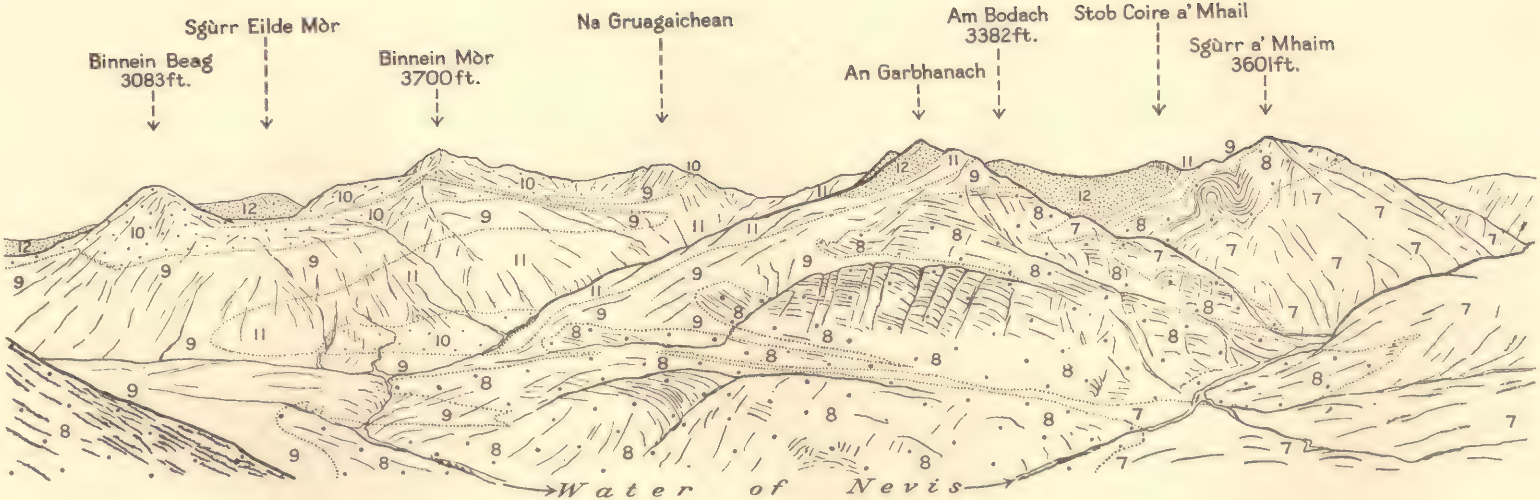


FIG. 12. View across Upper Glen Nevis, looking south

7, Leven Schists (youngest); 8, Glen Coe Quartzite; 9, Binnein Schists; 10, Binnein Quartzite; 11, Eilde Schist; 12, Eilde Quartzite. For slides, see Sheet 53 and Figs. 14, 16 of current-bedding upon which these statements are based have all been taken from banded transition zones linking the quartzite and the schist concerned. The clarity of the evidence is illustrated in the drawings reproduced in Fig. 13, which can be verified in essence by any one who goes to see—that is, the figured or a comparable exposure is sure to be found at the various localities indicated. Anyone making a special study of the succession is advised to consult the writer's 1934 account which is in some particulars more detailed.

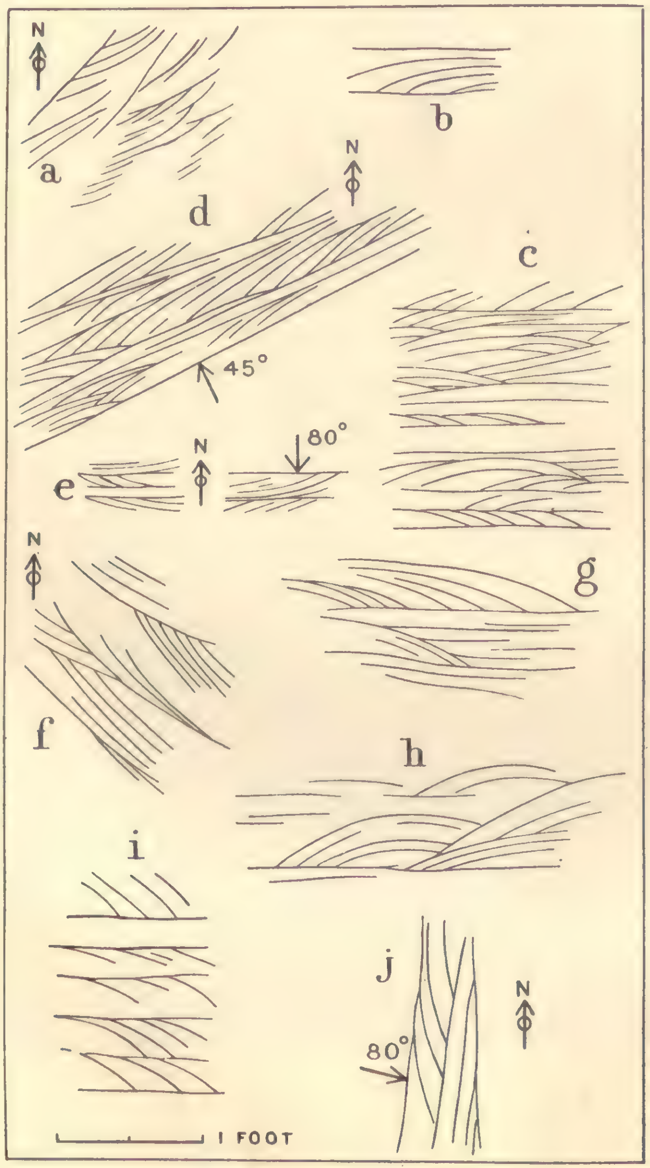


FIG. 13. Sketches of current-bedding

Structurally the district is of extreme interest. Its rocks lie wholly beneath the Ballachulish Slide, and are involved in a great recumbent anticline, the Kinlochleven Anticline, which intervenes between the Recumbent Synclines of Appin and Ballachulish. The north-westward close of this anticline, so far as Glen Coe Quartzite is concerned, is seen in the Tom Meadhoin Antiform of Figs. 8, 9, pp. 50, 51 and Section AA, Sheet 53. The close is here rising. The same north-westward close, so far as Eilde Quartzite is concerned, is seen in the Stob Coire na h-Eirghe and Garbh Bheinn Synform, north and south of Loch Leven. The close is here falling (Fig. 14, C,D ; Section AA, Sheet 53).

The north-westerly rise of the axial plane of the Kinlochleven Recumbent Anticline at Tom Meadhoin and the north-westerly fall of the same in Stob Coire na h-Eirghe and Garbh Bheinn are determined by the secondary synform of Stob Bàn (p. 47), responsible for the intervening outcrop of Ballachulish Core at Callert. Where, at Tom Meadhoin, the local core (Glen Coe Quartzite) of the Kinlochleven Recumbent Anticline rises to the surface to present itself as an antiform, this antiform is also an anticline in the sense that its Glen Coe Quartzite core is older than enveloping Leven Schists—a matter easily proved by attention to current-bedding. Where, at Garbh Bheinn, the local core (Eilde Quartzite) of the Kinlochleven Recumbent Anticline falls to the surface to present itself as a synform, this synform is an anticline in the sense that its Eilde Quartzite core is older than enveloping Eilde Schists—a matter again demonstrable by current-bedding.

Along Loch Leven all the outcrops from Glencoe House to Caolasnacon (Fig. 15) belong to the upper normal limb of the Kinlochleven Recumbent Anticline, and, apart from local complications, are shown by current-bedding to be right-way-up (Fig. 13a) ; while all the outcrops east of Caolasnacon, to at least two miles east of the head of the loch, belong either to the close, or in much greater part, to the lower, inverted limb of the Kinlochleven Recumbent Anticline, and are shown by current-bedding, again apart from local complications, to be upside down (Fig. 13c-e, g-i). This Kinlochleven Inversion, extending for at least four miles across strike, is more easily appreciated than any other example of the

Explanation of FIG. 13—*Sketches of Current-Bedding*

Sketches a, d, e, f and j, which represent current-bedding on a fairly flat surface, are treated as maps with the north point at the top. The remaining sketches, of current-bedding on fairly steep faces, are treated like strike-sections with the main bedding represented horizontally.

(a) Glencoe Quartzite youngs north-westward, away from Binnein Schist. Eastern side of the mouth of quarry at Rudha Cladaich, north shore, Loch Leven (Fig. 15, west).

(b) Glencoe Quartzite youngs downwards, away from Binnein Schist. Southern side of Glen Nevis, almost in a line with a shatter-belt or smash shown on Sheet 53 and Fig. 16.

(c) Binnein Quartzite youngs downwards towards Binnein Schist. Near northern shore, Loch Leven, half a mile east of Allt Nathrach (Fig. 15, east).

(d) Binnein Quartzite youngs south-eastward, away from Eilde Schist. Northern shore, Loch Leven, three-quarters of a mile west of Allt Nathrach (Fig. 15, east).

(e) Binnein Quartzite youngs northward, away from Eilde Schist. At junction of these formations, southern shore, Loch Leven opposite Eilean nam Ban (Fig. 15, east).

(f) Binnein Quartzite youngs north-eastward, away from Eilde Schist. Same junction as (e), but half a mile inland along strike and just outside Fig. 15, east.

(g) Eilde Quartzite youngs downwards towards Eilde Schist. Roadside, half a mile north-east of Caolasnacon (Fig. 15, east).

(h) Eilde Quartzite youngs downwards towards Eilde Schist, but at some distance from the contact. Roadside, 1¼ miles east-north-east of Caolasnacon (Fig. 15, east).

(i) Eilde Quartzite youngs downwards towards Eilde Schist. Near western junction, a little above deer-stalkers' path, 1½ miles north-east of Am Bodach and 3 miles north of Kinlochleven.

(j) Eilde Quartzite youngs eastward, towards Eilde Schist. Near eastern junction, close to same deer-stalkers' path as (i), but only one mile north-east of Am Bodach.

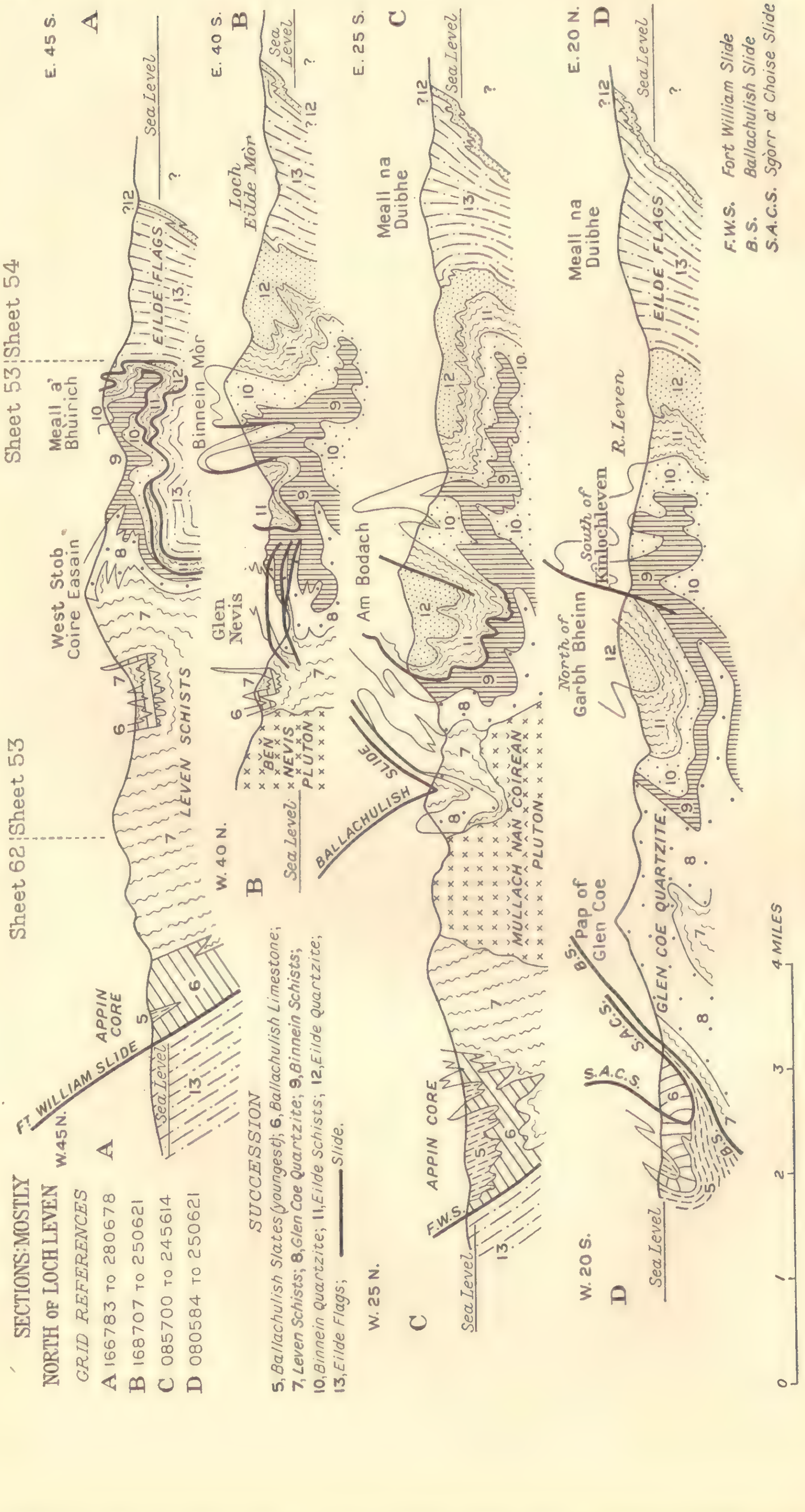


FIG. 14. Sections: mostly north of Loch Leven

kind elsewhere in the world ; and it is particularly obvious in the coastal strip reaching for half a mile west of the head of Loch Leven towards Allt Nathraich. In fact extensive inversion here can actually be demonstrated to a non-geologist, once the latter has learnt to appreciate the significance of current-bedding. Everything is convenient. A motorist can safely park his car in a discarded bend of the now straightened main road a little east of the entrance to a private drive leading up to Mamore Lodge. He can then descend by a path (shown in Fig. 15, east, near the dip 15i) leading to a boathouse on the lochside. Almost every exposure of quartzite that he sees is current-bedded ; and invariably the current-bedding is inverted (Fig. 13c).

Another point of special interest is the manner in which outcrops tend to swing from south-west to south-east as they approach the great pitch-depression of Glen Creran (p. 23). Along most of Loch Leven the deflection is fairly closely associated with the course of the loch. A shatter-belt runs along Loch Leven, Loch-Eilde Mòr and Loch-Eilde Beag, but is more likely to have been located by the twist than to have caused it. The manner in which the south-west strike reasserts itself in Meall Mòr, south of the entrance to Glen Coe, suggests that the complication belongs to what may be called the schist tectonics of the district. Two miles south of Kinlochleven the main swerve of strike roughly follows the course of the Boundary-Fault of the Cauldron-Subsidence by Coire Mhorair (Fig. 24), Stob Mhic Mhartuin (Fig. 26) and Stob Beinn a'Chrùlaiste (Fig. 28). Here undoubtedly the abruptness of the change of strike has been accentuated by the faulting, but it would be hazardous to suggest that the twist in essence has been caused by the Cauldron-Subsidence.

We have said above that the Kinlochleven Recumbent Anticline intervenes between the Recumbent Synclines of Ballachulish and Appin. It seems to be accompanied in this position by another recumbent anticline at a slightly lower level (Bailey 1934a, p. 507). This lower fold has been called the Stob Recumbent Anticline after an eastern Stob Coire Easain (nat. grid 308731) in Sheet 54(Geol.). It will be discussed later under the heading *Problem at Blackwater Reservoir, p.* 108.

Stratigraphy from Leven Schists to Eilde Flags.—The *Leven Schists* (7) are in the main a great mass of pale greenish-grey, pelitic mica-schist, with porphyroblasts and patches of biotite and innumerable fine white or yellowish stripes ($\frac{1}{16}$ to $\frac{1}{8}$ inch thick) of fairly quartzose material. Apart from this persistent lamination, most of the group is extremely homogeneous, and ribs of quartz-granulite and quartzite are restricted to a narrow transitional banded zone bordering the Glen Coe Quartzite. Here some quartzose ribs are slightly calcareous, while dark carbonaceous pelitic seams are common, often interlaminated with yellowish quartzose material.

The constancy of the Leven Schists adjoining the Mam na Gualainn (nat. grid 116626) to Stob Coire Easain (nat. grid 234727) outcrop of Glen Coe Quartzite north of Loch Leven is to some extent discounted by the marked change of facies that has been described in chapter vi south-west of the Ballachulish Pluton. Still, if the mica-schist outcrops that occur east of this Glen Coe Quartzite outcrop were really repetitions of the Leven Schists, one would expect them somewhere to show the pale green porphyroblastic, laminated type—but they do not.

Garnet is usually quite inconspicuous near Loch Leven, but increases towards Glen Nevis.

The *Glen Coe Quartzite* (8), seen in Pls. II, 2, V and XIII, 2, is fine-grained. In the Pap of Glen Coe and Mam na Gualainn, either side of Loch Leven, it is markedly felspathic and often grey-weathering. On Tom Meadhoin to the west and beyond the Lairigmòr valley to the north it is comparatively pure and white. Towards Stob Coire Easain, while maintaining this pure character, it carries occasional small ferriferous spots.

In Tom Meadhoin and at intervals along the western border of the main outcrop current-bedding shows that the Glen Coe Quartzite is older than the Leven Schists—in conformity with the evidence already given that the Appin Quartzite is older than the Appin Limestone. The shore road (shown in Fig. 15, but not in Sheet 53) south of Loch Leven traverses the foot of the Pap of Glen Coe and exposes abundant current-bedding (often associated with slumping) right across the outcrop of the quartzite. This consistently youngs south-westwards, that is towards the Leven Schists. About 7000 feet of quartzite are seen in the traverse, which makes one suspect reduplication by sliding.

It is rather hard to find current-bedding just adjacent to the Binnein Schist, for bedding here tends to be regular. Still, definite examples occur at the eastern side of the entrance to a large road-metal quarry at Rudha Cladaich north of Loch Leven (Fig. 13a and Fig. 15, west) ; and others are seen almost immediately to the east in a cutting of the main road. Here the current-bedded quartzite carries interbedded mica-schists and merges with the Binnein Schist alongside. Some of the marginal quartzose bands at Rudha Cladaich are distinctly gritty in the sense of containing large clastic grains, a most unusual feature in the Glen Coe, Binnein or Eilde Quartzites. These gritty bands extend to the south side of the loch and characterise a zone some 50 feet thick, which is traceable all told for more than two miles along outcrop. Localities south of the loch, from a third of a mile to a mile inland measured along strike, show occasional current-bedding which invariably youngs south-westwards away from the Binnein Schist. See also Fig. 13b.

The *Binnein Schists* (9) are dark grey mica-schists with evenly disseminated biotite and with occasional or frequent ribs of quartzose granulite. These ribs are particularly numerous near outcrops of quartzite (both Glen Coe and Binnein). They there form part of banded transition zones containing some calcareous beds and dark carbonaceous seams, such as occur in the banded transition zone that connects the Leven Schists with the Glen Coe Quartzite. Garnet is seldom conspicuous near Loch Leven, but increases north-eastwards through Glen Nevis.

Before the value of current-bedding was appreciated Carruthers distinguished the Binnein from the Leven Schists, not only by difference of character in bulk, but also by difference of marginal relationship with Glen Coe Quartzite. Thus along the Water of Nevis he compared the Glen Coe—Leven contact at its furthest-west point (in the north bank, W.S.W. of Upper Steall, Fig. 16) with the Glen Coe—Binnein contact 1½ miles further east, downstream from the junction with Allt Coire na Gabhalach ; and again the same two contacts in the great cliff of Sgùrr a' Bhuic a mile further north. In both cases he found the passage from solid quartzite to banded mica-schist relatively abrupt at the Binnein Schist margin. In a country much complicated by slides the significance of this contrast is, of course, difficult to assess.

The Binnein Schists have a main outcrop and four subsidiary ones. The main outcrop borders the Glen Coe Quartzite on its eastern, generally south-eastern, side for 13 miles from Allt a' Chaolais, (nat. grid 156596), south of Loch Leven, to the map margin, east of Stob Coire Easain. South of Loch Leven, and for a short distance to the north, it lies between outcrops of Glen Coe and Binnein Quartzites. Northwards, as we shall presently see, Binnein Quartzite temporarily fails, and for the next nine miles, to Glen Nevis and back again to near Binnein Mòr, Binnein Schists almost always come directly into contact with Eilde Schists. The junction of these two similar schist groups is indicated approximately on Sheet 53 by a broken heavy line. It very likely is a slide, but may be no more than a stratigraphical hiatus. From the neighbourhood of Binnein Mòr north-east to the map margin, Binnein Quartzite reappears in force, to serve once more as south-east boundary to the main Binnein Schist outcrop. This latter, north of upper Glen Nevis, is about a mile wide.

The four subsidiary outcrops of Binnein Schist lie almost entirely within the main outcrop of Binnein Quartzite, upon which Kinlochleven stands. The Binnein Quartzite here belongs to the reversed limb of the Kinlochleven Anticline and all four outcrops of Binnein Schist rise into it as demonstrable antiforms. Further detail is reserved for the description of structural details in the Kinlochleven, Binnein Mòr and Binnein Beag districts. At present we need do little more than locate the four outcrops on the map.

The first and most westerly outcrop is the only one to cross Loch Leven. It has been followed for three miles from the Fault-Intrusion of Glen Coe (nat. grid 175593) by way of Allt Nathrach, north of the loch, to terminate as a broken antiform west of Sgòr an Fhuarain (nat. grid 176638).

The second (see Kinlochleven Antiform, p. 104) is only ¾ mile long and is mostly exposed in the precipitous face overlooking Kinlochleven from the south (nat. grid 186611). The Binnein Schist here passes under Binnein Quartzite at about 1500 feet above sea level ; whereas at the roadside north of the River Leven (nat. grid 187623) it disappears under the same formation at about 50 feet.

The third is quite small, an obvious antiformal exposure above the Lairigmòr track south-west of Sgòr an Fhuarain (nat. grid 173632).

The fourth reaches 2½ miles from Sgòr an Fhuarain (nat. grid 183635) to Binnein Mòr (nat. grid 207664). For half a mile it is bounded on the north-west by Eilde Schist through local failure of Binnein Quartzite.

The *Binnein Quartzite* (10) is always remarkably pure, and almost always white-weathering. In the Kinlochleven neighbourhood ferriferous spots are a marked feature, but they are local and do not extend far into Garbh Bheinn on the south. They reappear, however, to a trifling extent in the detached outcrop at Caolasnacon (Fig. 15). The Binnein Quartzite can readily be distinguished from the Glen Coe Quartzite where the latter is felspathic, as in the Pap of Glen Coe and and Mam na Gualainn ; but the difference of character is doubtful north of the Lairigmòr valley, since here the Glen Coe Quartzite becomes purer and whiter.

The Binnein Quartzite has a two-mile-long outcrop extending along Allt Gleann a' Chaolais to terminate a little north of Loch Leven, as mentioned above. This outcrop will be termed in the sequel the Caolasnacon outcrop (Fig. 15). It lies west of the Garbh Bheinn Synform that holds in its axial belt the Eilde Quartzite outcrop of Garbh Bheinn, Stob Coire na h-Eirghe, Am Bodach and An Garbhanach. To the east of this synform the Binnein Quartzite rises again to the surface in a complex group of antiforms responsible for the white quartzite country of Kinlochleven, Sgòr an Fhuarain, Binnein Mòr, Binnein Beag and Meall a' Bhùirich. The Binnein Quartzite of this complex antiformal country serves as envelope to the four subsidiary outcrops of Binnein Schist that we have listed above.

It so happens that the roadside-lochside strip reaching across the axial belt of the Garbh Bheinn Synform, from half a mile west to a mile and a half east of Caolasnacon (Fig. 15), gives particularly convincing evidence regarding the age relations of Binnein Schists, Binnein Quartzite, Eilde Schists and Eilde Quartzite. Consideration of this will follow immediately upon the brief statement given below regarding the characters and outcrops of the Eilde Schists, Eilde Quartzite and Eilde Flags.

The *Eilde Schists* (11) are indistinguishable lithologically from the Binnein Schists. They have two outcrops ; one surrounds the Eilde Quartzite outcrop of the Garbh Bheinn Synform, the other, west of the Binnein Mòr group of antiforms, runs from the Fault-Intrusion of Glen Coe north-east to cross the River Leven above Kinlochleven, then swings flatly from Meall an Doire Dharaich past Mamore Lodge to steepen up and continue north-east to Meall a' Bhùirich.

The *Eilde Quartzite* (12) is a felspathic quartzite indistinguishable lithologically from the Glen Coe Quartzite as seen in the Pap of Glen Coe. Like the Eilde Schists it has two outcrops : the synformal one mentioned above from Garbh Bheinn to An Garbhanach ; and another sufficiently localised on Sheet 53 if we say that is passes by the outflow of Loch-Eilde Mòr.

The *Eilde Flags* (13) are micaceous quartzo-felspathic flags with very conspicuous bedding. Lithologically they are of what Scots geologists commonly call the psammitic Moine type. Recognisable detrital grains are very rare in the group as a whole, but W. B. Wright recognised a gritty quartzose group with large grains of quartz and felspar near the margin of the flags on both sides of the River Leven east of Allt na h' Eilde. The Eilde Flags have a single two-mile-wide outcrop extending in a general north-east direction through Loch-Eilde Mòr and Loch-Eilde Beag.

Stratigraphical Detail : West and East of Caolasnacon (Fig. 15).—As mentioned above exposures on the two sides of Caolasnacon farm establish the age relations of Binnein Schists, Binnein Quartzite, Eilde Schists and Eilde Quartzite. The Binnein Schist margin of the Caolasnacon outcrop of Binnein Quartzite is exposed on the hillside above the road half a mile west of the farm (Fig. 15, west). Bare rock leads up to the junction. At some distance from the schists the quartzite is massive and white, with frequent current-bedding always younging towards the Binnein Schist. Nearer the junction, the quartzite becomes grey-white and transitional to the banded edge of the Binnein Schists. In this position one good example of current-bedding may be noted. It too youngs towards the Binnein Schists.

On the nearby south shore of Loch Leven, Binnein Quartzite again shows current-bedding, always younging towards the Binnein Schists, but no examples were found in what could be claimed as passage beds.

The other, eastern margin of the Caolasnacon outcrop of Binnein Quartzite is against Eilde Schist, and supplies abundant clear evidence that the quartzite youngs away from this schist. The best exposures are close to the road a little east and west of a bridge 300 yards east of Caolasnacon (Fig. 15, east). Here current-bedding can be found in pure quartzite right up to the margin of the mica-schist, and also in a bed of quartzite interstratified with this mica-schist. In all cases the verdict is the same. The Binnein Quartzite youngs away from the Eilde Schist.

Thus the Binnein Quartzite at Caolasnacon has two stratigraphical sides. It is older than the Binnein Schists to the south-west and younger than the Eilde Schists to the north-east.

The Eilde Schists of the Caolasnacon outcrop are present in bulk making a prominent ridge overlooking Allt Gleann a' Chaolais above the bridge just

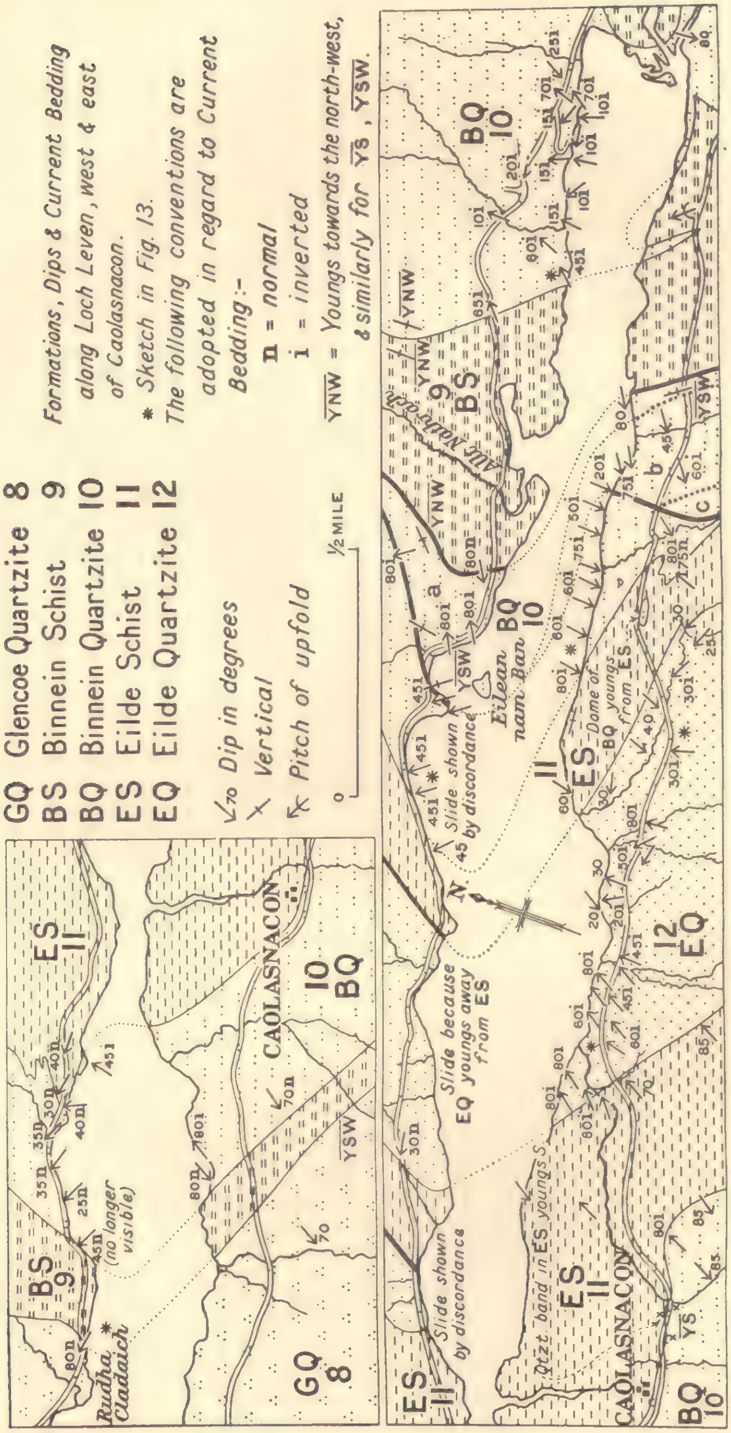

GQ Glencoe Quartzite 8
BS Binnein Schist 9
BQ Binnein Quartzite 10
ES Eilde Schist 11
EQ Eilde Quartzite 12
70 Dip in degrees
Vertical
Pitch of upfold
0
½ MILE
Formations, Dips & Current Bedding along Loch Leven, west & east of Caolasnacon.
* Sketch in Fig. 13.
The following conventions are adopted in regard to Current Bedding:-
n = normal
i = inverted
YNW = Youngs towards the north-west, & similarly for YS, YSW.
Rudha Cladaich
(no longer visible)
CAOLASNACON
Slide shown by discordance
Slide because EQ youngs away from ES
Eilean nam Ban
Dome of BQ youngs from ES
Qtzt band in ES youngs S.
Allt Nathrach
N
a
b
c
GQ 8
BS 9
BQ 10
ES 11
EQ 12
YSW
YNW
YS

FIG. 15 (West above, east below). Formations, dip and current-bedding west and east of Caolasnacon mentioned. The road crosses them as shown in Fig. 15, east, and half a mile from the farm reaches quartzite once again ; but this is Eilde Quartzite, older than the Eilde Schists.

Current-bedding is common in this Eilde Quartzite along and near the road, and it is everywhere inverted (Fig. 13g, h ; Fig. 15, east). Special attention may be directed to an exposure at the actual western margin of the quartzite in the artificially deflected course of Allt Gleann a' Chaolais (shown in Fig. 15). Current-bedding is here perfectly displayed in quartzite bands forming part of a transition zone leading south-west to Eilde Schists. Its attitude is exactly the same as in neighbouring massive quartzite free from mica-schist intercalations ; and it shows definitely that the Eilde Quartzite youngs towards the Eilde Schists.

Thus the Eilde Schists at Caolasnacon have two stratigraphical sides. They are older than the Binnein Quartzite to the south-west and younger than the Eilde Quartzite to the north-east. What follows supplies confirmation.

The Eilde Quartzite outcrop which has now been reached can be seen on the slopes of Garbh Bheinn (south of Fig. 15) to be disposed in a synform pitching rather steeply to the north-west ; and wherever current-bedding has been observed it is inverted. This Garbh Bheinn Synform is, as we have pointed out, the falling close of the Kinlochleven Recumbent Anticline. Its downward close is exposed in the outcrops of many individual beds. It is asymmetric, with steeper dips (60° to 80°) on its south-western side and gentler dips (25° to 40°) on its north-eastern side. It is asymmetric also in having a greater thickness of quartzite in the steep south-western limb than in the gently inclined north-eastern limb. This is almost certainly due to sliding.

Eilde Schists reappear from under the Eilde Quartzite of the Garbh Bheinn Synform, 1¼ miles E.N.E. of Caolasnacon. Current-bedding (Fig. 13h) has been found near, but not immediately at, the junction. It is inverted as noted above.

Across this second or eastern outcrop of Eilde Schists, Binnein Quartzite is reached once more, and is of the same type as at Caolasnacon. It also shows the same age-relations to the Eilde Schists, for abundant current-bedding youngs away from the adjacent schist (Fig. 13e, f). Moreover, the junction is almost certainly a transition. The age-relations are exhibited, not only at the main contact, but also at a little dome of inverted Binnein Quartzite indicated by a note in Fig. 15, east.

Before the main outcrop of Binnein Quartzite is passed one enters into complications due to slides (p. 106).

Tectonic Detail : Glen Coe Quartzite.—Up to now the broad structural features of the district have been sketched with only sufficient detail to make the stratigraphical succession intelligible. Brief accounts follow, which concentrate on structural features grouped under convenient headings.

The close of the Kinlochleven Recumbent Anticline as exhibited in the Tom Meadhoin Antiform is sufficiently illustrated in Figs. 8, 9.

The great thickness of Glen Coe Quartzite in the Pap of Glen Coe, 7000 feet all younging south-west, has already been given as reason to suspect reduplication by slides. In Mam na Gualainn, across Loch Leven, the quartzite is divided into two by what looks like an isoclinal upfold of Leven Schist—but the locality has not been searched for current-bedding, and there may be undetected sliding. The apparent upfold pitches south-west.

Emerging towards the north-east at lower structural levels we find a whole succession of conspicuous, albeit minor, folds, sometimes much modified by

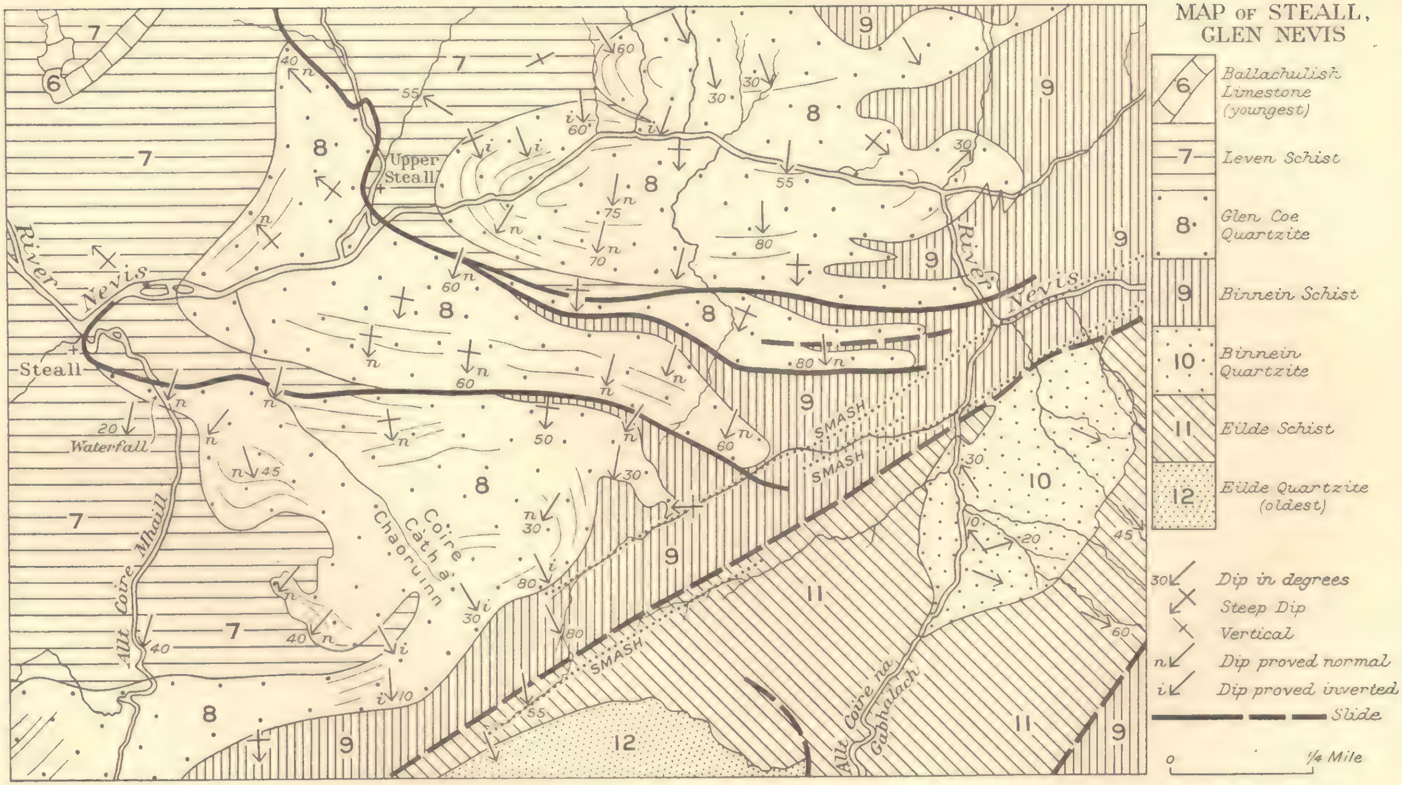


Fig. 16. Map of Steall, Glen Nevis

slides. The first noteworthy example is a handsome recumbent anticline seen on the north face of Stob Bàn. It is cored by Binnein Schist and closes to the north-west.

Then, in Sgùrr a' Mhàim, a steep synform appears followed by an antiform (Pl. V). As the succession youngs in Pl. V from left to right (*cf.* Figs. 12, 13b) the synform is obviously cored by older rocks, and so in a sense is an anticline ; and *vice versa* with the antiform.

Across Allt Coire Mhaill, on the slopes of An Garbhanach leading down to the Steall reach of Glen Nevis, the Glen Coe Quartzite is folded to and fro (and even more strikingly slid) along with its bordering Leven and Binnein Schists (Fig. 16). The result, though on a quite moderate scale, is definitely spectacular as may be gathered from Fig. 12 which is based on photographs. The map, Fig. 16, follows in most particulars the original six-inch survey by the writer in 1907 ; but it is modified to an important extent by insertion of slides and certain other features borrowed from a new six-inch map published by G.S. Johnstone (1955). The two maps have not been compared by the writer in the field, so that certain unimportant additional changes may prove desirable. It may perhaps be recalled that the writer had already alluded to "a number of obvious minor slides, which occur in connection with recumbent folds of the Glen Coe Quartzite on the southern side of Glen Nevis" (1934a, p. 488, footnote) ; but he had never time, since realising the value of current-bedding, to re-examine the exposures. Johnstone undertook this task and was rewarded by finding the Glen Coe Quartzite to be right-way-up practically everywhere from the latitude of Upper Steall ruin in Fig. 16 southward until the upper limb of the little recumbent syncline of Coire Càth a' Chaoruinn is reached. This firmly establishes the three slides he has traced. (He himself does not join the middle with the lower slide as is shown in Fig. 16, but this is a trifle.) It also shows that all three slides are thrusts, in the sense that they cut out hypothetical reversed limbs. The uppermost of them is well exposed at the base of Steall waterfall, where it serves as an obviously transgressive boundary between uninverted Glen Coe Quartzite (8) and underlying Leven Schist (7), younger, of course, than itself.

When northwards the River Nevis is reached, to and fro folding sets in again. The folds are of no great extent, and the pitch continues steeply towards the south. This involves the quartzite in a compressed zig-zag outcrop. After two such folds are passed, what we may call the Sgùrr a' Bhuic Antiform rises to the surface with a core of Binnein Schist. This is crossed by the north margin of Fig. 16, and is at first considerably obscured by landslip. Glen Coe Quartzite on the north-west side of the schist core continues the main outcrop ; while, on the south-east side, it extends into what must be a sharp synform. Quite probably the upper reversed limb of this synform may be replaced by a thrust, but the locality has not been searched for current-bedding. The steep pitch that brings the Sgùrr a' Bhuic Antiform into view soon moderates. Accordingly the Binnein Schist of the antiformal core outcrops for a couple of miles in a north-east direction.

Then, at Sgùrr Choinnich Mòr, from beneath this Binnein Schist, Glen Coe Quartzite rises in accord with the usual southerly pitch. This tectonically low-level portion of the quartzite is itself very strikingly folded to and fro, in folds that always pitch more or less to the south-west. An observer who climbs the quartzite ridge where it leaves Sheet 53 (6 miles S.S.E. of Spean Bridge railway station), will see, looking back towards Stob Coire Easain, three minor, but very attractive, recumbent folds, superimposed.

Tectonic Detail : Garbh Bheinn Synform and Associated Slides.—We must briefly recapitulate some of the structural findings set out in our stratigraphical account of the Caolasnacon neighbourhood, south of Loch Leven (p. 98) : the heart of the Garbh Bheinn Synform, a mile E.N.E. of Caolasnacon (Fig. 15, east), is occupied by Eilde Quartzite, of which the synformal disposition is self-evident ; this quartzite is everywhere upside down ; there is probably unlocated sliding in the north-east limb of the synform, for the quartzite is manifestly thinner here than in the south-west limb ; Eilde Schist emerges from under the Eilde Quartzite both on the north-east and south-west, and in the latter position is connected with the quartzite by obvious stratigraphical transition. On both sides again the Eilde Schist is followed by Binnein Quartzite younging away from it.

Across the loch to the north complications are indicated on Sheet 53 by three heavy black lines, two of them broken. These are indexed as slides. Let us consider them from west to east.

The *first heavy line*, west of the Caolasnacon narrows, is inserted to indicate the observed failure of the western (Caolasnacon) outcrop of Binnein Quartzite shortly after crossing the loch. From here onwards for half a dozen miles to the north-east, Binnein Schist comes directly into contact with Eilde Schist. Though indexed as a slide, the hiatus mapped may quite possibly be an original stratigraphical feature. What is certain is that the Caolasnacon outcrop of Binnein Quartzite belongs to a stratigraphical intercalation. In the first edition of this memoir it was wrongly thought that since this Caolasnacon outcrop stopped north of Loch Leven it functioned as the core of an antiform passing under flanking mica-schists, both of them of Binnein Schist age. This is impossible because current-bedding shows that the quartzite, so long as it is present, youngs away from the eastern mica-schist (Eilde of Fig. 15) and towards the western (Binnein). The old view also held that the quartzites exteriorly flanking the mica-schists formerly met overhead, both of them of Glen Coe age. This too is contradicted by current-bedding : the Eilde Quartzite of Garbh Bheinn and Stob Coire na h' Eirghe is seen to be older than the mica-schist (Eilde) bounding it on the west ; while the Glen Coe Quartzite of the Pap of Glen Coe and Mam na Gualainn is seen to be younger than the mica-schist (Binnein) bounding it on the east.

Sheet 53 and Fig. 16 show an outcrop of Binnein Quartzite exposed in the valley of Allt Coire na Gabhalach near its junction with Glen Nevis. The thickness of this quartzite need only be small, for the general dip follows roughly the slope of the ground. Shearing is intense, and no indication of current-bedding has been found. It is, however, almost certain that the quartzite lies at a considerably lower structural level than that occupied by the Eilde Quartzite outcrop terminating in An Garbhanach (*cf.* Fig. 12) : and it seems likely that it is a local patch on the line that has been hypothetically drawn to separate Binnein and Eilde Schists. A mile to the south-south-west this line is located beyond question by reappearance of Binnein Quartzite as explained on p. 108.

The *second heavy line* represents an indubitable slide, " shown by discordance " as noted in Fig. 15. It is a scenic feature, serving as upper limit to an outcrop of Eilde Schist which divides the Stob Coire na h' Eirghe outcrop of Eilde Quartzite into two unequal parts before reaching Loch Leven. The part below this Eilde Schist corresponds with the Garbh Bheinn outcrop across the loch. The part above, that is to the north-west, is thrown into a conspicuous isoclinal fold closing downwards towards the loch, beyond which it does not reappear. The lower limb of this synformal fold is seen in the landscape to be almost entirely cut out by the slide under consideration.

The *third heavy line*, continuing north-eastwards from Loch Leven to An Garbhanach, also represents a slide, but one that had to await examination of current-bedding for its detection. In Fig. 15 it is noted as a " slide because Eilde Quartzite youngs away from Eilde Schist." The stratigraphical correlations involved in this note are taken from the previous Section on *Stratigraphical Detail*: *West and East of Caolasnacon*. The younging evidence is admittedly scanty, but (1) at the top of the steep slope leading down to Allt Nathrach, (2) in Allt Nathrach itself and (3) on the arête north-east of the cairn on Am Bodach current-bedding was observed in Eilde Quartzite close to, or fairly close to, its junction with Eilde Schist ; and in all three localities the current-bedding of the quartzite younged away from the schist.

We now pass on to show that marginal sliding along this line is reassuringly demonstrable on strictly local evidence east of An Garbhanach, irrespective of stratigraphical correlations. A deer-stalkers' path crosses An Garbhanach roughly from north to south, passing obliquely over the whole width of the outcrop of what is interpreted as Eilde Quartzite. All the way the quartzite is steep, with abundant exposures of current-bedding. This latter youngs consistently north-westwards (Fig. 13i), until within a few yards of the mica-schist that follows to the south-east. Here at last the current-bedding youngs unmistakably south-eastwards (Fig. 13j). It is impossible for a formation to behave in this fashion without the help of a slide on one side or other of the exceptional evidence. The most obvious explanation, according also with that derived from consideration of Garbh Bheinn, is as follows : at An Garbhanach Eilde Quartzite is disposed in a fold between two outcrops of Eilde Schist, younger than itself ; and in the south-east limb of this fold it has been almost, though not quite, cut out by sliding.

Tectonic Detail : Kinlochleven.—The main object of this and the two following discussions is to furnish details concerning the antiformal belt of Binnein Quartzite which outcrops from the Cauldron-Subsidence of Glen Coe through Kinlochleven, Binnein Mòr and Binnein Beag to reach the map margin at Meall a' Bhùirich. These localities can be found on Sheet 53. On Fig. 15 the belt, in two main outcrops, extends from the head of Loch Leven to past Eilean nam Ban.

Immediately south of Kinlochleven, what may be called the Kinlochleven Antiform carries Binnein Schists steeply up for 1500 feet into overlying Binnein Quartzite. The upfold is sectioned in an abrupt hill-face which has an average slope of 45°, so that structural relations are exposed to perfection. In fact in many conditions of lighting they can easily be followed by an observer standing below on the road, for instance at the Kinlochleven bus garage. The quartzite of the arch pitches strongly south-eastwards to pass under Eilde Schists, which, close at hand, as Sheet 53 shows, furnish the core of a complementary synform. This latter is well displayed west of the antiform on the hill-face visible from the town. At the top of the hill it is an open obvious synform affecting successive beds of the quartzite. Lower down it becomes steeply isoclinal.

To get a complete picture of the structure east of the Kinlochleven Antiform, permission has to be obtained to examine the light-railway cutting inside the Aluminium Factory grounds. A pipe-line, which lies outside the grounds on the east should next be visited.

In the railway cutting the quartzite of the east limb of the Kinlochleven Antiform is bent up in an open synform, which in turn is followed by an open antiform easily recognised on the hillside. Both these folds pitch somewhat steeply southwards. Beyond to the east there is no more folding, and the Binnein Quartzite of the east limb of the last-mentioned antiform continues to dip steeply, as seen to perfection along the pipe-line, until it passes under Eilde Schist. Everywhere, in the railway cutting and along the hillside and pipe-line, abundant current-bedding shows that the Binnein Quartzite, though it overlies Binnein Schists and underlies Eilde Schists, is older than the former and younger than the latter. The succession has been overturned in the great Kinlochleven Inversion. It may be added that just beyond the Eilde Schists outcrop, Eilde Quartzite, exposed in an alternative channel of the River Leven south of the main gorge, shows occasional current-bedding. This, in keeping with the rest of the evidence, youngs consistently towards the Eilde Schists and away from the Eilde Flags.

The south-westerly or southerly pitch, characteristic of the Kinlochleven Antiform and its flanking folds south of the town, gives place, in ground mapped by W. B. Wright across the River Leven, to north-easterly pitch. One result is that the outcrop of the Binnein Schist core of the Kinlochleven Antiform extends only a short distance beyond the River Leven. (It just reaches the head of Loch Leven in Fig. 15, east.) Its northern margin is exposed in the main road close to Allt Coire na Bà (east of Fig. 15). Here Binnein Schist passes northwards under Binnein Quartzite, of course upside down. We have already selected the quartzite exposures leading westwards from this point to the first reappearance of Binnein Schists, a quarter of a mile short of the Allt Nathrach bridge, as furnishing type examples of inverted current-bedding (p. 95).

In harmony, the hillside north of the termination of the exposed Binnein Schist core of the Kinlochleven Antiform shows Binnein Quartzite in a series of minor folds pitching gently north-eastwards under Eilde Schists. This impressive low-angled inversion continues across strike for a mile and a quarter, and is a prominent feature of Sheet 53. Eastwards, a quarter of a mile before reaching Meall an Doire Dharaich, the quartzite—schist junction bends down steeply to cross first the River Leven and then the pipe-line of which we have already spoken. The sharp downward bend of the quartzite is a prominent scenic feature. It is due to a modified continuation of the antiform seen a little east of the Kinlochleven Antiform south of the river.

Westwards, between Mamore Lodge and Sgòr an Fhuarain, the low-angled inversion of Eilde Schist over Binnein Quartzite again comes to an end, but in this case in a sharp upturn, which is due to a modified continuation of the synform immediately west of the Kinlochleven Antiform south of the river. The result of the flat zone, bounded to the east by a downturn and to the west by an upturn, is to give the Eilde Schist a markedly zig-zag outcrop. Sheet 53 shows that the Eilde Quartzite outcrop follows the same pattern, incidentally demonstrating *inversion* to the extent of a mile and a half, which of course is only part of the total Kinlochleven Inversion responsible for the detached outcrop of Eilde Quartzite running through Garbh Bheinn and Am Bodach.

The next exposure of Binnein Schists to be noted is shown on Sheet 53 three-quarters of a mile north of the head of Loch Leven, just north of General Wade's Military Road south-west of Sgòr an Fhuarain (nat. grid 173632). Its antiformal character is obvious as also is the inverted current-bedding of its Binnein Quartzite envelope.

Beyond this we reach the largest of the Binnein Schist outcrops that are associated internally with the complex Kinlochleven spread of Binnein Quartzite. In Fig. 15 it is shown crossing Loch Leven at Allt Nathrach. Approached from the east it presents no difficulty. Let us start on the south side of the loch.

Here the outcrop of Binnein Schist under consideration lies 600 yards W. of that belonging to the core of the Kinlochleven Antiform ; and, as we have already noted, the intervening Binnein Quartzite is disposed in a clearly recognisable synform. Accordingly we may be sure that the schists of the two outcrops meet a short distance underground. In keeping with this our present outcrop, as shown in Fig. 15, is reduced to half its inland width just before reaching the loch by north-westerly pitch.

North of the loch the continuation of our Binnein Schist outcrop emerges at the shore from under Binnein Quartzite, the latter characterised by inverted current- bedding (Fig. 13d). Inland the same junction is particularly well exposed beyond an unrewarding precipitous wooded slope, and shows to perfection a banded transition zone with abundant current-bedding always younging from Binnein Quartzite to Binnein Schist.

Further still, on the west slope of Sgòr an Fhuarain, the Binnein Schist outcrop terminates, and Binnein Quartzite is seen folding over it antiformally.

Here simplicity ends. Much of the Binnein Quartzite outcrop to the west has been complicated by slides, only one of which is shown on Sheet 53. In Fig. 15 an additional one is indicated ; and there may be several.

The more westerly of the two, so far as the ground south of the loch is concerned, has only recently been discovered by W. G. Hardie (1955). South of Fig. 15 he traced it for half a mile as a transgressive boundary between Binnein Quartzite and Eilde Schist, responsible for quick south-eastward reduction of the former's outcrop almost to nothing. (No one has recently re-examined this outcrop where it recuperates, still further south.) Within Fig. 15 Hardie followed his western slide northwards into the heart of the Binnein Quartzite outcrop as western boundary of Area (c)—to be explained below. On the south coast of Loch Leven he could not locate it; but it seems fairly certain that it does cross the loch as shown in Fig. 15 to join up with a similarly situated western slide long recognised on the north coast. Here the slide is very clear, for it is responsible for discordances of dip in the Binnein Quartzite on its two sides.

Between the two slides as drawn on Fig. 15, Areas (a), (b) and (c) have been distinguished by attention to current-bedding.

> In Area (a) current-bedding youngs away from the Binnein Schist outcrop that we are considering. North of Loch Leven, Area (a) occupies the whole space between the two slides. South of the loch it is at most 100 yards wide. (Current-bedding, younging S.W., is very well exposed in Binnein Quartzite adjoining Binnein Schist alongside each of the two main roads, north and south of the loch respectively.)
>
> In Area (b) current-bedding youngs towards our Binnein Schist outcrop. It is not known whether or no Area (b) anywhere reaches the Binnein Schist margin.
>
> In Area (c), first recognised by Hardie, current-bedding youngs away from our Binnein Schist outcrop, from which it is separated by 400 yards occupied by Areas (b) and (a). Area (c) is only 400 yards long and 100 yards wide. Its western margin (the western slide) separates it obliquely from Binnein Quartzite which is younging in the opposite direction.

It will be understood that it is the orientation of current-bedding in Area (a) that has led to the drawing of the eastern slide that is shown alone in Sheet 53. The quartzite of all three areas, (a), (b) and (c), is of the pure white Binnein type, the same as occurs beyond the Binnein Schist outcrop that lies to the east. As stated above, this Binnein Schist outcrop in Sgòr an Fhuarain is seen to be antiformal. Therefore we should expect that, if there were no sliding, the age relations of the flanking quartzites should be identical. In actual fact, as we have noted, the quartzite on the east, in junctions that are unmistakably unslid, youngs towards the mica-schist (p. 106) ; while the quartzite on the west youngs away from the same—and the junctions are not of a kind to preclude the possibility of sliding.

Tectonic Detail : Binnein Mòr and Binnein Beag.—The present district, mapped by W. B. Wright, extends the Kinlochleven district north-eastwards from Sgòr an Fhuarain to Binnein Beag. The behaviour of the Eilde Schist and Eilde Quartzite outcrops along its south-east margin continues what we have described north of Kinlochleven so simply that it can be understood on consulting Sheet 53 without further comment.

We have already noted how the Allt Nathrach outcrop of Binnein Schist (Fig. 15, east) terminates north-eastwards antiformally on the west side of Sgòr an Fhuarain (Sheet 53), with Binnein Quartzite crossing over it. On the east side another outcrop of Binnein Schist, which we may name after Na Gruagaichean, terminates south-westwards in the same quartzite setting, but without local indication as to whether it closes up or down. Followed to Binnein Mòr, however, its antiformal character becomes self-evident. The Binnein Quartzite of this mountain is thrown into a picturesque succession of two synforms and two antiforms with gently inclined axes. The antiforms have very steep south-east limbs and quite gently inclined north-west limbs. Current-bedding demonstrates convincingly that, as at Kinlochleven, the antiforms and synforms affect quartzite already upside down, part of the Kinlochleven Inversion.

Returning towards Sgòr an Fhuarain, we find in Allt Coire na Bà, a section across the Gruagaichean strip of Binnein Schist, that we now know serves as core to a steep antiform. The outcrop of the schist is here 100 yards wide, and it is flanked by outcrops of Binnein Quartzite, about 300 yards wide on either side. Both these flanking outcrops are proved by current-bedding to young towards the intervening Binnein Schist and away from external outcrops of Eilde Schist. As shown in Sheet 53 the Eilde Schist outcrop on the north-west reaches across strike to the Eilde Quartzite outcrop of Am Bodach and An Garbhanach ; while that on the south-east reaches across strike to the Eilde Quartzite outcrop of Sgùrr Eilde Mòr.

Here then we have in epitome the structure of the whole Kinlochleven—Binnein Mòr region : a central antiform with Binnein Schist core, flanked either side by an inverted succession of Binnein Quartzite, Eilde Schist and Eilde Quartzite. Of course if we look at details we find a complication, namely the slide previously discussed that serves as south-eastern boundary to the Eilde Quartzite outcrop of Am Bodach.

Let us now face other complications. From the Cauldron-Subsidence of Glen Coe as far north as Na Gruagaichean the Binnein Quartzite of the antiformal complex is always bounded externally by mica-schist older than itself, that is, Eilde Schist. At Binnein Beag things are different. The schist to the east is still Eilde Schist, as demonstrated for instance by current-bedding in the quartzite margin at Meall Doire na h-Achlais ; but that to the west and north is now Binnein Schist according again to evidence from current-bedding. In keeping with this, where the outcrop of this Binnein Schist sweeps eastwards half across the quartzite outcrop on the north-east slope of Binnein Beag, the deviation is due to south-westerly pitch (admittedly in some cases steep). Also, in an antiform indicated on Sheet 53 by outcrop lines the current-bedded quartzite is seen, correspondingly, to be upside down.

The solution to the puzzle is afforded by study of the most north-westerly portion of the Binnein Beag outcrop of quartzite. At about a quarter of a mile south-west of the mountain summit this portion of the outcrop begins to separate as a distinct band from the main mass by insertion of a strip of mica-schist. The resultant band of quartzite, at first 400 yards wide, eventually dwindles to nothing a mile and a quarter to the south-west. Current-bedding is well exposed in a stream draining north of west midway between Binnein Beag and Binnein Mòr. It is seen in quartzite intercalations in the mica-schist and incessantly across the whole width of the quartzite under consideration ; and it invariably youngs north-west. Accordingly :

(1) The mica-schist of the insertion is Eilde Schist, obviously connecting with the Eilde Schist belt that further south flanks the Binnein Quartzite complex of Sgòr an Fhuarain externally on its north-west side.

(2) The Binnein Quartzite band to the north-west is a stratigraphical intercalation between this Eilde Schist and Binnein Schist to the north-west again.

(3) Where the Binnein Quartzite band fails to the south-west it allows Eilde Schist to make direct contact with Binnein Schist.

Whether the south-west disappearance of the Binnein Quartzite band is stratigraphical or tectonic, it is impossible to say. On Sheet 53, a heavy broken line is inserted to mark approximately the cross-country position of the direct junction between Eilde and Binnein Schists. It leads, as drawn, to the locality north of Loch Leven, three-quarters of a mile north-west of Caolasnacon, where undoubted Binnein Quartzite reappears.

Another heavy broken line marking a hiatus, likely a slide, is inserted on Sheet 53, for a mile and a half south-west from Binnein Beag. At first it separates the Eilde Schist tongue of Binnein Beag, younging north-west, from the much folded quartzite of Binnein Mòr. Further south it brings the same Eilde Schist, for three-quarters of a mile along strike, into contact with the Binnein Schist core of the Na Gruagaichean Antiform. Still further south, on the Na Gruagaichean ridge, its place is taken conspicuously by Binnein Quartzite in normal succession.

Tectonic Detail : Meall a' Bhùirich.—Special complications present themselves in Meall a' Bhùirich on the eastern border of Sheet 53, and require for their discussion knowledge of a considerable area lying to the north-east. Here two points may be mentioned : (1) rapid thinning leads to disappearance of Eilde Quartzite of the type outcrop as it approaches and crosses the continuation of Glen Nevis ; and (2) north-east pitch at the very margin of the map carries Eilde Quartzite and associated Eilde Schists under Eilde Flags, the last we see of the Kinlochleven Inversion. A little further information is given in the following section K.

K. PROBLEM AT BLACKWATER RESERVOIR

The western end of Blackwater Reservoir just enters Sheet 53 half way along its eastern margin ; and the problem referred to in the title of this section is the stratigraphical and structural position of four bands of metamorphic sediments outcropping east of the type Eilde Flags and west of the reservoir. The four formations have been given local names to avoid premature correlation : Stob Quartzite, next to the Eilde Flags ; Reservoir Schists ; Reservoir Quartzite ;

Reservoir Flags. The name Stob has been taken from *eastern* Stob Coire Easain in Sheet 54 (nat. grid 308731).

Carruthers was of opinion that these four formations were successively older than the Eilde Flags ; but here more recent work seems to have proved him mistaken. Current-bedding at eastern Stob Coire Easain demonstrates that the Stob Quartzite youngs away from Eilde Flags at what appears to be a transitional contact (Bailey 1934a, p. 502). There is very considerable inversion at this point, for the Stob Quartzite pitches under Eilde Flags in a well exposed synform and antiform which together measure more than a mile across strike.

It is highly probable : that the Stob Quartzite is Eilde Quartzite, coalesced perhaps with Binnein and Glen Coe Quartzites ; that the Reservoir Schists are Leven Schists, with which, despite higher metamorphism, they agree rather closely in character ; that the Reservoir Quartzite is Stob (Eilde) Quartzite reappearing ; and that the Reservoir Flags are Eilde Flags.

The *Stob* (?*Eilde*) *Quartzite* is fine-grained, considered as a sediment, though metamorphism has sometimes led to coarse recrystallisation. It is in part white, massive and pure ; in part felspathic. Its outcrop in the River Leven is nearly a third of a mile wide ; but elsewhere it is much narrower until eastern Stob Coire Easain is approached in Sheet 54. Further on again it vanishes. Search for current-bedding in the River Leven has proved unavailing.

The *Reservoir* (?*Leven*) *Schists* have a central band characterised by conspicuous biotite pseudomorphs after actinolite. This band has been named by Carruthers the " Ermine Rock," and has been traced by him for twelve miles along strike north-east from the River Leven. It is like certain developments of the Leven Schists far to the south-west between Glen Creran and Glen Etive. West of the Ermine Rock Carruthers describes the Reservoir Schists as garnetiferous, and east of it as non-garnetiferous and usually red.

The *Reservoir* (?*Eilde*) *Quartzite* is fine-grained and yellowish. It is best exposed at the foot of the reservoir and on Stob Beinn a' Chrùlaiste three miles to the south.

The *Reservoir* (?*Eilde*) *Flags* are like the Eilde Flags. They are cut off to the east by the Moor of Rannoch Pluton.

When we turn to consider structure we note (*cf.* Sheets 53, 54 ; Figs. 28, 29 ; Bailey 1934a, pl. xv) :

(1) According to the above suggested correlations, based partly on current-bedding and partly on character, the Eilde Flags of the type outcrop are bounded, both to north-west and to south-east, at the present surface of erosion, by Eilde Quartzite, younger than themselves.

(2) North-east pitch carries these type Eilde Flags in the Kinlochleven Inversion north-westwards over type Eilde Quartzite of the north-west outcrop, both past the outlet of Loch-Eilde Mòr and at Meall a' Bhùirich on the eastern margin of Sheet 53.

(3) South-west pitch carries them in the Stob Inversion south-eastwards over presumed Eilde Quartzite of the Stob outcrop, both at eastern Stob Coire Easain in Sheet 54 and, 10 miles further south, from Altnafeadh to Càm Ghleann, where the effect of pitch is supplemented by downthrow within the Cauldron-Subsidence of Glen Coe.

Accordingly, if we were restricted to localities enumerated above, the natural interpretation would be to equate the Kinlochleven and Stob Inversions and to picture the Eilde Flags of the type outcrop as everywhere floating on one and the same band of Eilde Quartzite. Mapping, however, further north-east, for which we are mainly indebted to Carruthers (1923, fig. 1, p. 18 ; modified slightly in Bailey 1934a, pl. xv and p. 507), has shown that this is too simple an interpretation. Here we can only state dogmatically the outcome of the most recent work on the subject.

The Kinlochleven Inversion north-west of the Eilde Flag type outcrop in Sheet 53 is on a higher structural level than the Stob Inversion south-east of the same. Both these inversions mark the lower limbs of recumbent anticlines, the Kinlochleven Recumbent Anticline above, and the Stob Recumbent Anticline, below. The Eilde Flag cores of these two anticlines join in the type outcrop of this formation *within the limits of Sheet* 53, but are separated north-westwards by the quartzites and mica-schists that, in Sheet 53, outcrop between Loch-Eilde Mòr and Am Bodach. Furthermore, the Kinlochleven Inversion shrinks greatly towards the north-east. Thus it is found in Sheet 54 that the younger formations of Meall a' Bhùirich soon fail to penetrate south-eastwards under the Eilde Flags continuing the type outcrop. For further information the reader is referred to the descriptions quoted above, with the proviso that the position of a hypothetical slide separating Binnein and Eilde Schist north of Meall a'Bhùirich (*in* Bailey 1934a, pl. xv) requires minor adjustment. E. B. B.

CHAPTER VIII

METAMORPHIC ROCKS

LOCHABER AND APPIN (*Resumé*)

A brief summary will now be given of the results which have been set forth in some detail in chapters iv to vii concerning the schists on the south-east side of Loch Linnhe (see also Bailey 1910, 1934a, 1938).

Stratigraphy.—The following stratigraphical sequence has been established, with the youngest placed top. Internal age relations have been furnished by current-bedding in four quartzite members. Acknowledgment of invaluable assistance from Carruthers, Vogt, Buckstaff, Rove and Tanton has been made in chapter ii and more fully in (Bailey 1930, 1934a).

0. Lismore Limestone (dark-grey)—*youngest of the list*
1. Cuil Bay Slates (black)
2. Appin Phyllites (with large proportion of flaggy quartzite)
3. Appin Limestone (dolomitic, cream-coloured, pink, etc.)
4. Appin Quartzite
    - (massive gritty—4 where separated)
    - (striped transition zone—4′ where separated)
5. Ballachulish Slates (black)
6. Ballachulish Limestone (youngest part, dark-grey and pure ; middle, calcareous schist ; oldest, cream-coloured)
7. Leven Schists (grey with banded edge against 8)
8. Glen Coe Quartzite (fine-grained)
9. Binnein Schists (grey)
10. Binnein Quartzite (fine-grained)
11. Eilde Schists (grey)
12. Eilde Quartzite (fine-grained)
13. Eilde Flags (psammitic Moine type of Scots geologists—quartzo-felspathic with micas) —*oldest of the list*

The propriety of introducing the Lismore Limestone of Shuna into the above list has been debated on p. 41. As regards thicknesses, the Appin Limestone, apart from interbedded phyllite and quartzite, may not be much more than 100 feet. All the other formations appear to be considerably thicker, with the Appin Quartzite, if we take its two parts together, 1000 feet, and the Leven Schists and Eilde Flags, each 2000 feet or more.

The listed formations seem to be linked seriatim by passage zones to form a continuous whole.

Facies is wonderfully constant, except that the Leven Schists in their outcrop reaching south-west from the Ballachulish Pluton are in large measure interbanded with quartzitic beds and dark pelitic seams.

Metamorphism.—Metamorphism increases in an easterly direction, ranging from a grade in which biotite is inconspicuous or absent to one in which garnet is prominently developed. It also increases downwards as shown at faulted juxtapositions in Glen Coe and at Ben Nevis.

Recumbent Folds.—For a broad appreciation of the structure of the district it is convenient to adopt an arbitrary grouping of its formations into two major stratigraphical units. The younger of these consists of Ballachulish Limestone (6) and all younger formations ; the older consists of Leven Schists (7) and all older formations. The outcrops of the younger unit are shown in black in Fig. 17 ; those of the older unit are dotted with a density corresponding with structural position.

The two stratigraphical units are interfolded in great recumbent folds ; and it is pleasant to recall that the first step towards recognition of large-scale re-

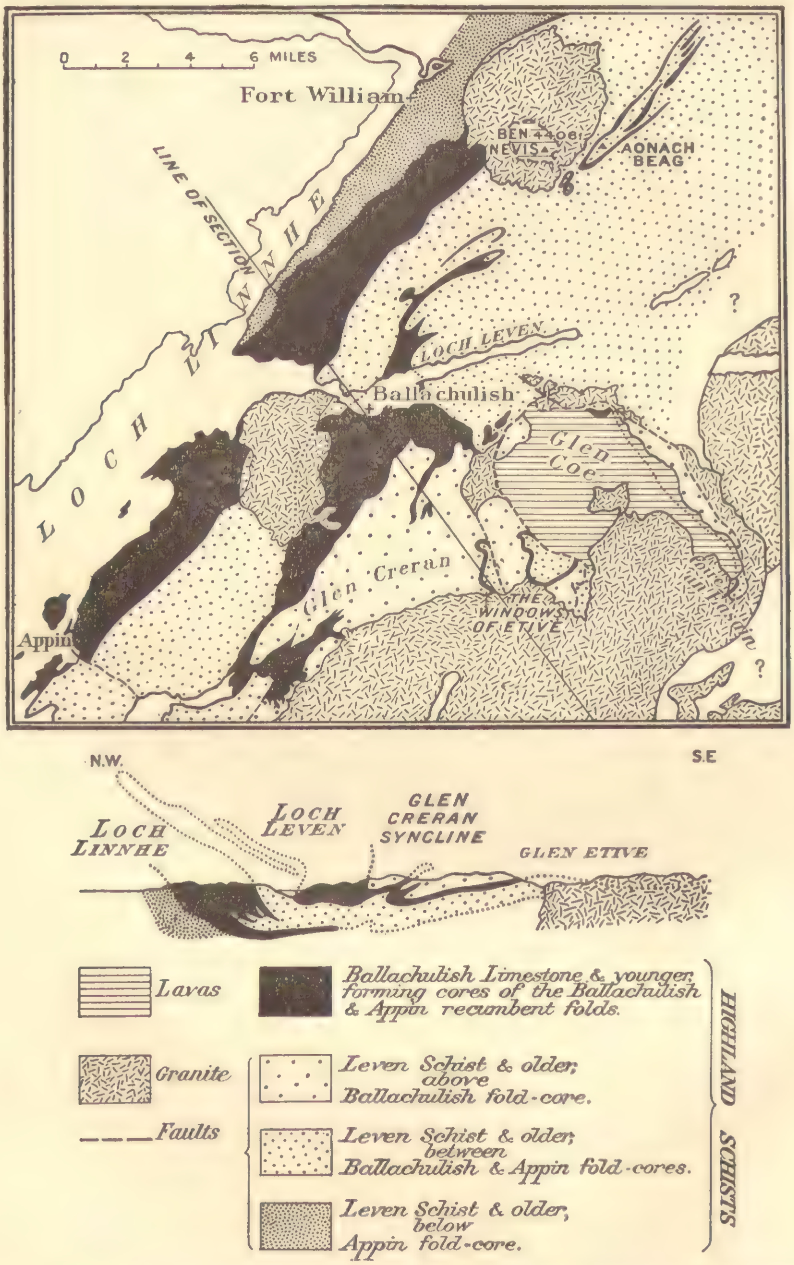

0 2 4 6 MILES
Fort William
LINE OF SECTION
LOCH LINNHE
BEN NEVIS 4406
AONACH BEAG
LOCH LEVEN
Ballachulish
Glen Coe
Glen Creran
THE WINDOWS OF ETIVE
Appin
?
?
N.W.
S.E
LOCH LINNHE
LOCH LEVEN
GLEN CRERAN SYNCLINE
GLEN ETIVE
Lavas
Granite
Faults
Ballachulish Limestone & younger forming cores of the Ballachulish & Appin recumbent folds.
Leven Schist & older; above Ballachulish fold-core.
Leven Schist & older; between Ballachulish & Appin fold-cores.
Leven Schist & older, below Appin fold-core.
HIGHLAND SCHISTS

FIG. 17. Map and Section showing the structure of the Highland Schists and the positions of the cauldron-subsidences of Glen Coe and Ben Nevis

cumbent folding in the district was taken by Maufe in 1905 (pp. 19, 87—a discussion of structural terms is given in chapter iii). Among these recumbent folds, synclines can be distinguished from anticlines through their cores consisting of relatively young formations. Three main recumbent synclines have been given proper names, to wit, the Appin, Aonach Beag and Ballachulish Synclines. All three gape towards the north-west and close towards the south-east.

It has been found convenient in dealing with these synclines to define and name their cores with an arbitrary stratigraphical limitation. Thus the terms Appin, Aonach Beag and Ballachulish Cores (when used as proper names in this memoir) stand for the cores of the Appin, Aonach Beag and Ballachulish Synclines, *in so far as* these cores consist of Ballachulish Limestone and younger formations. On this understanding the black band running between the Ben Nevis Pluton and Appin in the map of Fig. 17 represents the outcrop of the Appin Core ; the thick black lines about Aonach Beag represent the outcrop of the Aonach Beag Core ; and the complicated black belt that divides near Ballachulish represents the outcrop of the Ballachulish Core.

The Appin Core is the lowest of the three. In section it is shown in Fig. 17 between Loch Linnhe and Loch Leven. The Aonach Beag Core seems to be a minor affair in an intermediate position. According to this view it does not come to earth along the line of section in Fig. 17, but finishes in the air as a digitation or finger-like projection a little below the Ballachulish Core—a slightly different alternative is discussed on p. 47. The Ballachulish Core, the highest of the three, is shown in the Fig. 17 section as going underground in Meall Mòr, south of Loch Leven, to reappear in the recumbent fold of Achnacon (p. 78) and in the Windows of Etive. This last exposure does not mark its eastern limit, since it has been recognised again in Coire an Easain (p. 82). The distance from the west margin of the outcrop of the Ballachulish Core, north of Loch Leven, to Coire an Easain is 13 miles measured south-east across the usual strike of folding ; and for twelve miles of this, Ballachulish Limestone underlies Leven Schists, older than itself.

The stratigraphical-structural convention adopted above in relation to core-rocks leaves the Leven Schists and all older formations as envelope-rocks. In Fig. 17 these envelope-rocks are dotted, densely if they underlie the Appin Core, more openly if they intervene between the Appin and Ballachulish Cores, and more openly still if they overlie the Ballachulish Core.

The map of Fig. 17 thus depicts the Ballachulish Core as bent into a great basin (pitch-depression) which may be called after Glen Creran (it is loosely styled the Glen Creran Syncline instead of Synform in the accompanying section). The most striking evidence of this basin, which the map by itself affords, is the glimpse one gets of the eastward underground continuation of the Ballachulish Core, revealed in the Windows of Etive. In the field there is plenty of parallel evidence. Here we need only recall how the outcrop of the Ballachulish Core terminates to the north-west on the Stob Bàn ridge, midway between Loch Leven and Ben Nevis, where it is seen to lie along the axis of a secondary (that is later) synform, the narrowed representative of the Glen Creran Pitch-Depression (p. 47).

The envelope rocks between the Appin and Ballachulish Recumbent Synclines are disposed in a recumbent anticlinal complex, closing to the north-west and gaping to the south-east. In the Loch Leven district the outstanding feature is the Kinlochleven Recumbent Anticline with its core of Eilde Quartzite (12) extending to Am Bodach and Garbh Bheinn (Fig. 14, p. 94). Its inverted limb gives us the Kinlochleven Inversion, reaching fully 4 miles across strike and abundantly demonstrated by upside-down current-bedding. The Kinlochleven Inversion may be interpreted as belonging, not only to the lower limb of the Kinlochleven Anticline, but also to the upper limb of the Appin Syncline, and thus supplies good evidence for essential recumbency of the latter. Otherwise the essential recumbency of the Appin Syncline is mainly inferred from the close analogy which this fold bears to the Ballachulish Syncline, the great horizontal extent of which is abundantly clear.

The fate of the Kinlochleven Inversion, when traced north-east past Meall a' Bhùirich, and the relation between the Kinlochleven and the Stob Inversion at a lower structural level cannot be fully appreciated on evidence within Sheet 53 (p. 110).

Slides.—When attention is given to the map (Sheet 53) and the sections (Figs. 7, 14, pp. 48, 94), it is seen that the limbs of various recumbent folds are, in many instances, reduced by slides. Some of these slides are situated in the lower limbs of recumbent anticlines, and thus correspond with the thrusts so familiar in descriptions of mountain tectonics all over the world. To this category belongs the Sgòrr a' Choise Slide, S‴ of Fig. 7 ; but, strange to say, the two most important slides of the district, the Fort William Slide of Fig. 14 and the Ballachulish Slide, B.S. of Fig. 7, both lie in the lower limbs of recumbent synclines, and are therefore lags. Necessarily associated with this predominance of lags is a quite unusual tendency for reversed successions to escape much of the thinning that has affected nearby unreversed successions. Contrast, for instance, the two representatives of the Leven Schists (7), thick above, and thin below the Ballachulish Limestone (6) as exposed in the Windows of Etive (Fig. 7, G, H). Still another peculiarity of the local geology is the regularity of the thinning affected along the slides. In the North-West Highlands thrusting has often produced a jumble of formations with *Schuppen Struktur* between a main thrust mass and its foundation. Here, however, such thinned-out remnants as persist along slides are almost always in correct stratigraphical sequence. Finally, the sliding is not, at any rate in all cases, accompanied by mylonisation and retrograde metamorphism. It probably occurred at a temperature that allowed of concurrent recrystallisation.

Inversions.—The very extensive inversions of Sheet 53 invite comment. It is difficult to suppose that inversions, miles in cross-strike extent, have developed as a result of wholesale rotation from the normal position, through the vertical, to the inverted position. It seems much more likely that these great inversions have been accomplished piecemeal, like the fore and aft inversion of the " track " of an advancing military " tank ". In a paper entitled " Eddies in Mountain Structure " (Bailey 1938), it has been pointed out that this type of inversion might be expected to be coupled with development of extensive lags. The subject is very difficult, and is likely to be more fully understood when comparable structural associations have been identified and studied in other chains of folded mountains.

Secondary Folds.—An obvious feature of the sections illustrating the structure of Sheet 53 is that earlier-formed, recumbent folds and slides have suffered in places extensive corrugation of isoclinal type. Secondary, meaning relatively late, synforms are conspicuous in Aonach Beag, Stob Bàn, Callert and Glen Creran (Figs. 6-9). When these secondary folds started their existence the recumbent folds they affected had, very likely, already ceased to develop ; but there is no reason to suppose that this marked a general sequence of events : recumbent folding may still have been in operation even close at hand.

The secondary synform of Stob Bàn and the two secondary synforms which unite with it west of Mam na Gualainn strike and pitch south-west. They produce detailed deflections of strike in the various formations, but they leave the general grain of the country running north-east—south-west. When, however, the augmented Stob Bàn Synform swells to give the great Glen Creran Pitch-Depression south of Loch Leven, the outcrops between Bridge of Coe and Kinlochleven and between Stob Mhic Mhartuin and Càm Ghleann are swung through a right angle carrying their early foliation with them. Recumbent folding was probably continuing at the time this deflection was developed, for otherwise it is difficult to account for the recumbent fold marked by the limestone core above Allt na Muidhe reaching south-west from Glen Coe at Achnacon to Meall Lighiche.

Secondary Metamorphism.—Metamorphism connected with the secondary Aonach Beag Synform has left its mark in conspicuous strain-slip cleavage seen for instance in the Glen Nevis gorge (p. 24). It also seems likely that the metamorphism of many small intrusions of the Glen Creran district is connected with the secondary Glen Creran Synform. These schistose rocks, judging from their field distribution (p. 69), must have been intruded after movement along the Ballachulish Slide had come to an end.

Addendum.—After this chapter had been written a paper by Weiss and McIntyre has shown the need for further explanation—see p. 22. E. B. B.

CHAPTER IX

METAMORPHIC ROCKS

ARDGOUR DISTRICT

THE metamorphic rocks of the Ardgour district, north-west of Loch Linnhe in Sheet 53 (Geol.), were mapped by Grant Wilson, except those within a considerable triangle south-west of Sgùrr nan Cnamh and Amhainn Coir' an Iubhair, which were allotted to Maufe and the writer—both inexperienced recruits. The field-work was carried out under Peach as District Geologist ; but before the memoir was written Grant Wilson had died, Clough had succeeded Peach, and Maufe had gone to Southern Rhodesia. Clough took the writer for a brief investigation tour of the Glen Scaddle district, and then entrusted to him the preparation of the short account published in the 1916 memoir, largely based on preliminary notes by Wilson to successive *Summaries of Progress*. The district has since been made the subject of important papers by Drever (1936, 1939, 1940) and Harry (1954), and its borders have been touched by the Geological Survey working in the adjoining Geological one-inch Sheets 52, 61, 62, so that considerable additional knowledge has been obtained. At the same time there has been no Geological Survey revision, beyond a two-day re-examination of critical points, which was undertaken by the writer in conjunction with G. S. Johnstone in 1956. Johnstone and J. E. Wright had lately mapped Glen Loy, the next big glen north of Loch Eil in Sheet 62, where there is a basic pluton comparable with that of Glen Scaddle, Sheet 53 ; and they had reached interim conclusions regarding its intrusive and metamorphic relations, which are in some respects similar to those developed in the sequel.

In the absence of detailed local knowledge it has been thought wise to retain most of the old description, including its quotations from *Summaries of Progress*, in this new edition, printing it in small type, and to append comments to establish contact with up to date research. It has been a great encouragement to realise how valuable Wilson's pioneer work has proved. It must be remembered that it was accomplished rapidly, much of it before the close of the last century and that the geology is of quite exceptional difficulty. It has proved impossible in a short chapter to do full justice to the more modern work, and readers must consult the originals, more particularly for petrological descriptions and discussions.

ALTERED SEDIMENTS AND STRUCTURAL RELATIONS

In the main the metamorphic rocks are altered sediments, but they also inlude the Glen Scaddle complex of epidiorite and other igneous rocks, the Sgùrr Dhomhnuill mass of augen-gneiss farther to the west, and numerous small lenticles of hornblende-schist. (1916 edition)

The West Highland Unit of the Geological Survey has reported that an injection area starts at about twelve miles west of Sheet 53 and increases in intensity eastwards (Sum. Prog. 1931, p. 63; Kennedy 1946, see our Fig. 40; Phemister 1948, p. 31). It has also stated specifically that the Sgùrr Dhomhnuill augen-gneiss is an injection product rather than an igneous rock (Sum. Prog. 1932, p. 58 ; 1934, p. 68). It is now realised that much of the western part of Sheet 53 north-west of Loch Linnhe lies within the injection area entered in Sheet 52. On the map as published certain zones of " felspathised sedimentary gneiss " have been shown around the Glen Scaddle Pluton and along the Great Glen Fault. These will be discussed separately (pp. 124, 127). What is meant by the western injection-complex may be gathered from the description given in 1931 : injection " is especially obvious in a pelitic or semipelitic host. There is every variation between schists with pegmatitic or granitic strings and lenticles, lit-par-lit injection-gneisses and permeation-gneisses ". It has been found by A. G. MacGregor and W. Q. Kennedy that the main injection episode antedated the emplacement of the Strontian granodioritic pluton, the edge of which crosses Gleann Feith 'n Amean on the west margin of Sheet 53 (Sum. Prog. 1932, pp. 106-9).

Drever as often as not speaks of the Glen Scaddle " epidiorite " as diorite-gneiss (1940, p. 152). Most of it, however, is free from metamorphic foliation. Perhaps diorite or gabbro-diorite would be a better term for the rock since according to Drever it often retains unaltered pyroxenes. In the present description, to keep contact with the published map, the term " epidiorite " will be retained, but always between inverted commas. Moreover Teall has said that a specimen submitted to him (S 8233) is epidiorite in " structure and composition " (Sum. Prog. 1899, p. 40). By this he meant a basic non-schistose igneous rock with secondary hornblende.

> The metamorphic sediments of this district are of the following main types :
>
> (a) Siliceous gneisses of ' Moine ' type, with a considerable proportion of felspar and mica accompanying the quartz ; these represent banded, impure, arenaceous sediments.
> (b) Highly micaceous gneisses ; these represent argillaceous sediments.
> (c) Quartz-granulites ; these represent exceptionally pure sandstones.
> (d) Marble ; this is of restricted occurrence and represents a thick, pure limestone or dolomite.
>
> The structural and stratigraphical relations of these various types are very imperfectly known. Their variations of dip and strike are sufficiently indicated on the map. (1916 edition)

At the northern boundary of Sheet 53, dips in the main outcrop of the siliceous gneisses (a) are often as low as 20° or 15°, though they become steep towards the micaceous gneisses on the north-west and Loch Linnhe on the south-east. The belt of low dips is about six miles broad, and reaches south-westwards for two to six miles until Cona Glen is approached, beyond which lies the Glen Scaddle " epidiorite ". So much is clear from Wilson's mapping. North-eastwards, as G. P. Leedal has pointed out (1952, pp. 37-8), the same " flat belt " can be followed for an additional twenty-five miles without coming to an end. The Cona strip, which interrupts the " flat belt " to the south-west. is about a mile wide and characterised by very steep dips and a west-north-western strike that parallels the outcrop of the Glen Scaddle complex. This and further related complications to the south-west will be discussed under heading (d).

Beyond the western boundary of the map MacGregor and Kennedy have found that, " where the country rocks have a regional strike nearly normal to the margin " of the Strontian Pluton west of its crossing of Gleann Feith 'n Amean in Sheet 53, " they have been swung round into conformity and now strike parallel to the outer margin of the complex—*e.g.* north of Strontian " (Sum. Prog. 1932, p. 115). The continuation of this approximate conformity is very marked in the course of the quartz-granulite outcrop (c), which mostly lies in Sheet 53. The swing is presumably due to magmatic pressure exerted by the pluton.

(a) The siliceous gneisses form the bulk of the country. As far south as Glen Gour " the chief type is a grey flaggy rock, with bands of varying thickness, and lighter and darker in tint, according to the presence of more or less black mica. Felspar and white mica are always present" (Wilson *in* Sum. Prog. 1898, p. 65). South of Glen Gour the flaggy character of what appears to be the continuation of these siliceous gneisses is lost, owing to an intricate puckering of the bedding planes. In this southern district the crystallisation of the gneisses is exceedingly coarse. (1916 edition)

Drever (1940, p. 151) correlated the main outcrop of siliceous gneisses (including the part mapped by Grant Wilson as " felspathised sedimentary gneiss " bordering the Glen Scaddle "epidiorite") with the Upper Psammitic Group of Moines established by Richey and Kennedy in the Morar district further north (1939). Rightly or wrongly, this view has also been advanced by Leedal further north-east (1952, pp. 36, 38), and by Harry in Ardgour itself (1954, pp. 287, 308). The last-named bases his correlation on certain calc-silicate ribs (quartz, basic plagioclase, epidote, garnet) which he has found in a marginal position relative to the outcrop of highly micaceous gneisses (b) (1954, p. 288, pl. xiv). By analogy these calc-silicate ribs lead him to correlate the sedimentary background of the micaceous gneisses (which are much granitised) with the Pelitic Group of Morar, which has been shown by current-bedding in its home region to be older than the Upper Psammitic Group. He then proceeds to interpret these micaceous gneisses as rising in an anticline from under their psammitic associates (1954, p.291). He tacitly assumes, it would appear, that there has been no great inversion and that an anticline must be an antiform.

Structural relations will be further discussed under headings (c) and (d). Meanwhile it may be noted that Drever has indicated four localities for calc-silicate ribs (quartz, basic plagioclase, pyroxene or hornblende, garnet) outside Grant Wilson's "felspathised" zone, but far from marginal to the micaceous gneisses (b) (1940, fig. 3, pp. 144, 146).

(b) The highly micaceous, or pelitic, gneisses occur near the western border of the map, and their outcrop, so far as it is included in the present district, terminates in a tongue extending southwards from Glen Gour across Glen Tarbert. A common type is muscovite-biotite-gneiss— " a coarsely crystalline rock with muscovite and biotite in large flakes, and with quartz and felspar, which may be scattered either more or less regularly throughout, or may be arranged in layers, knots, and lenticles of varying size. The rock in places is flaggy, and alternates with layers of granulitic quartz-schist of Moine type, while in other places it becomes massive and coarse, and assumes the appearance of a foliated igneous rock. In certain parts of the present area it is much traversed with knots, strings and veins of quartzo-felspathic material, sometimes carrying muscovite or biotite, or even both micas, and the crystalline texture is often coarse " (Wilson *in* Sum. Prog. 1904, p. 66). In places muscovite is quite inconspicuous, and the rock is then a biotite-gneiss. The material of the tongue which reaches south from Glen Gour affords a good example of this biotite-gneiss. (1916 edition)

The above description, if translated into modern terms, means that much of the band shown from the northern margin of Sheet 53 to beyond Glen Tarbert as pelitic Moine gneiss has suffered greatly from injection. Harry has modified its boundaries, more especially west of Lochan Dubh where he has transferred a considerable portion to the psammitic category. He has then interpreted the remainder (by far the greater part) as " composite granitic gneiss with a foundation of pelitic Moine Schist " (1954, p. 285, pl. xiv). In his mapping, what he decides to call composite granitic gneiss is about three times as abundant as what he leaves as injected pelitic schist, otherwise termed " oligoclase-biotite-quartz-gneiss " ; and it shows a distinct tendency to occupy a central position in the combined outcrop. He further points out that his composite granitic " gneiss develops a subordinate amount of augen-gneiss ". Thus in some slight measure his composite gneiss agrees with what Wilson mapped as " augen-gneiss (Sgùrr Dhomhnuill) " ; but Harry states that the summit of Sgùrr Dhomhnuill is composed of composite granitic gneiss devoid of augen (1954, p. 286)—in fact in his map he stops his augen ornament a mile to the south-west. E. B. B.

(c) The quartz-granulites are only shown separately on the map in a belt reaching south across Glen Tarbert to Cilmalieu, and in small isolated patches, apparently outliers, on Meall a'

Chuilinn and Maol Odhar further east. The main outcrop is flanked on both sides by banded, impure, siliceous gneisses of type (a), while the detached outcrops are completely surrounded by rocks of this character. At the head of Glen Galmadale the main outcrop swings round to the east and thus comes across the line of the minor outcrops already mentioned. This renders it probable that the tongue of micaceous gneisses (b), which terminates on the southern slopes of Glen Tarbert, marks the core of a fold, since it occupies a symmetrical position midway between the main and minor outcrops of quartz-granulite (c).

It is quite uncertain whether the siliceous gneisses of type (a) lying on the west and south of the main outcrop of quartz-granulite are on the same horizon as those on the east and north which come into contact with the micaceous gneiss (b). A good example of the interfolding of the western siliceous gneisses and the quartz-granulite is afforded on the mountain west of Maol Odhar. The crystallisation of the quartz-granulite is often exceedingly coarse, reminding one of the structure of glacier ice. H. B. M., E. B. B. (1916 edition)

The quartz-granulite (c) is relatively untouched by injection. The fact that its patches on Meall a' Chuilinn and Maol Odhar look like outliers has always made it probable that the belt of psammitic gneiss (a) and composite pelitic gneiss (b), separating them from the main outcrop, is antiformal—the same conclusion as has been later reached by Harry, but on rather more satisfactory grounds.

A problem is presented by the three-sided nature of the main outcrop of siliceous gneisses (a) as presented in Sheet 53. On one side we have the micaceous gneisses (b) ; on another the quartz-granulites (c) ; and on still another the marble-bearing group (d). No firm answer to this problem can be given. It is possible, for instance, that the quartz-granulites (c) outcrop in the surrounds of the Glen Scaddle " epidiorite," but not with sufficiently marked character to be separated by Grant Wilson from associated siliceous gneisses. At first sight this view seems supported by Drever, who has used the name quartzite for everything he saw of Grant Wilson's siliceous gneisses in the Glen Scaddle country ; but he has explained that he calls quartzo-felspathic rocks quartzite so long as " the amount of quartz present is distinctly greater than that of felspar " (1940, pp. 147, 161). Other alternatives suggest themselves, for instance that the marble-bearing group (d) may be introduced by a sedimentary or tectonic discordance. Quartzite will presently be mentioned in group (d), but its associates seem to negative correlation with that of group (c).

(d) The Ardgour Marble was discovered by Mr. Wilson in 1902. It consists of a thick bed or beds of crystalline marble weathering pale grey [one bed measures 23 ft (Drever 1939, p. 502)]. The outcrops lie between Glen Gour and Glen Scaddle. Specimens examined by Dr. Flett (S 11176-9 and 11181) have been found to contain calcite, forsterite, colourless pyroxene, felspar, garnet, sphene and graphite in very variable proportions. [Drever adds wollastonite, scapolite, phlogopite, etc., but seems to suggest that forsterite is confined to baked carbonated serpentine.]

The marble is everywhere closely associated with portions of the Glen Scaddle igneous complex. It is accompanied in some of its outcrops by a thinly bedded series of slightly calcareous grey pelitic sediments, containing quartzose bands. These sediments have quartz veins developed along their bedding planes, but their degree of regional metamorphism is certainly not very high. Dr. Peach (*in* Sum. Prog. 1904, p. 66) has accordingly suggested that they have been protected through having been contact-altered by the Glen Scaddle intrusions prior to the period of movement. (Compare the protection of hornfels round the augen-gneiss of Inchbae, Ross-shire, first interpreted by Peach. Clough, Crampton, Flett 1910 ; 1912, chaps. v, vi.) As will appear immediately it is certain that the introduction of the Glen Scaddle Complex antedated a large part of the schist-making movement ; it is doubtful, however, whether it is older than the whole of the movement. In one locality the dioritic rock is crowded with inclusions of quartzite, gneiss, etc., including some of pelitic character containing much kyanite [corrected to sillimanite, Drever 1940, p. 145 ; *cf.* (S 41717)]. Here the foliation of the containing rock is indistinct, and it seems as if some of the inclusions may have been foliated before their immersion in the igneous magma. (1916 edition)

This last observation was due to Clough and the writer. It was based upon an exposure within a fork of the Bealach Choire nam Muc stream-system. The stream junction, resulting in this fork, can scarcely be distinguished as such on the geological Sheet 53 ; but it occurs at Nat. Grid 962659 at the head of a half-mile strip of alluvium, which last is easy to identify both on Sheet 53 and in the field. Drever has illustrated the locality with a large-scale map extending 700 yd north-west of the stream junction (1940, p. 148). His map covers the type area, including the best exposures of the sedimentary associates of the Ardgour marbles found anywhere in the Glen Scaddle district.

A specially good marble outcrop runs for 300 yd along the more north-easterly of the two streams of the fork, and there are several others ; but, most of the sediment seen is non-calcareous pelite and quartzite, and it usually occurs as enclosures in what is spoken of above as dioritic rock. The exposure to which Clough and the writer directed attention is near the more south-westerly stream, 200 yd upstream from the fork, and there are many like it.

One of the two days the writer spent with Johnstone in 1956 was devoted to this critical area. We took the precaution in advance to ornament the outcrops on Drever's map, which otherwise are very difficult to read. Anyone, however, without this map will find in Sheet 53 a rough and ready guide sufficient for intelligent sampling of the field evidence. Exposures are numerous and easily accessible, and clearly lie just about the margin of the Coire nam Muc outcrop of Glen Scaddle " epidiorite ".

Above we have referred to Peach's suggestion that the Ardgour marble and associated sediments had been " contact-altered by the Glen Scaddle intrusion prior to the period of movement ". It so happens that Peach, in conversation with Crampton over hand-specimens, had been the first to suggest the pre-movement date of hornfelsing round the Inchbae—Carn Chuinneag augen-gneiss of Ross-shire, an idea since brilliantly vindicated. It was natural therefore that he should hazard a similar interpretation in connexion with the hornfelses that Grant Wilson found adjoining the Glen Scaddle " epidiorite ". Now however, it is thought that this interpretation requires important adjustment, and that the regional metamorphism later than the Glen Scaddle " epidiorite " is of the nature of a minor recurrence.

This change of outlook started when Clough and the writer, as recorded above, suggested that some regional metamorphism antedated the intrusion of the " epidiorite," although we considered the degree of this pre-hornfels metamorphism to be " certainly not very high ". Drever, with incomparably fuller knowledge of the district, has also been satisfied " that in Ardgour the rocks have been subjected to regional metamorphism on two occasions separated by a period when a large mass of basic magma invaded and thermally altered the limestone-pelite group " (1940, p. 164). To the evidence already cited he added the observation " that relics of pelitic hornfels and limestone entirely enclosed in diorite-gneiss [his usual term for the Glen Scaddle " epidiorite "] are often flat-folded or highly contorted " (1940, p. 164). This, he pointed out, is " a feature of the Ardgour hornfelses which has no parallel in the Carn-Chuinneag area " (1940, p. 168).

In regard to the intensity of the pre-hornfels regional metamorphism, Drever was cautiously prepared to admit that it might have been considerably higher than Clough and the writer had envisaged. " The presence of basic plagioclase in the calc-silicate rocks not associated with the diorite-gneiss, and the development of sillimanite in the thin rare bands of pelitic schist at some distance from the diorite-gneiss, and the relative coarseness of grain exhibited by the quartzites are features," he says, " which might conceivably be ascribed to the effect of a more general regional metamorphism of a high (sillimanite) grade," (1940, pp. 163-4)—and of pre-hornfels date. The calc-silicate rocks here mentioned are the ribs referred to above under heading (a). The sillimanite is fibrolitic sillimanite, not the stout prisms common in the hornfelses, and it is associated " with injection or segregation veins principally composed of potash felspar ". Drever gives the locality as Glen Gour, one third of a mile from the margin of the " epidiorite " (1940, p. 147). He also points out that hornfelsing may have obliterated evidence of previous metamorphism, and argues that the final post-hornfels folding of the district was conducted at a moderate temperature since it has not developed garnet in the metamorphism of any rock that he regards as part of the Glen Scaddle " epidiorite " (1940, p. 164). After returning to Bealach Choire nam Muc with Johnstone in 1956, the writer is prepared to accept the suggestions quoted above from Drever's account, with the supporting comment that some of the hornfelses do look under the microscope as well as in the field as if hornfelsing had been imposed on previously foliated rocks (S 41714-5).

Drever has dealt rather fully with the petrology of both the calcareous and pelitic hornfelses. The more characteristic minerals of the former have been mentioned already. Those of the latter include garnet, sillimanite, spinel, cordierite, oligoclase, biotite, corundum (1940, p. 159). The reader is referred to the original accounts. Let us here concentrate on a matter upon which, so far as ultimate interpretation is concerned, agreement has not yet been reached. It concerns the " dioritic rock", recorded by Clough and the writer as " crowded with inclusions of quartzite, gneiss, etc". This problematical rock constitutes most of the exposures in the type area within the designated stream-fork of Coire nam Muc. It also, with varying composition, is stated by Drever, more generally, to be " one of the most characteristic rocks " that occur " in association with limestone " on the border of " the large epidiorite masses " (1940, p. 146).

For Clough and the writer, and again for Johnstone and the writer, this " dioritic rock " appears to be a marginal extension of the Glen Scaddle " epidiorite," enclosing and baking adjacent sediments through which in places it manifestly breaks. At the same time specimens sliced in 1956 from the Clough-Bailey exposure show that it is far from being normal Glen Scaddle " epidiorite " with pyroxenes and amphiboles. Instead it is an abnormal garnetiferous biotite-diorite rich in oligoclase accompanied by subordinate quartz and orthoclase (S 41716a, 41718). The garnet is sometimes associated with groups of minute grains of green spinel. Similar garnet and spinel are common in many of the abundant rock enclosures. Also some of the biotite of the diorite is micropoecilitic. There seems no doubt to the writer that the diorite here is an igneous rock, derived from the Glen Scaddle " epidiorite " magma much contaminated through reaction with its numerous enclosures.

This dioritic rock is apparently Drever's " oligoclase-quartz-garnet-chlorite-rock " (the chlorite secondary after biotite), which he treats as a local variety of what he calls in his text and on his map " sillimanite-gneiss". Of the latter he says (1940, p. 165), "apart from the general coarser grain of the composite gneiss the main difference between it and the relics of pelitic hornfels lies in the absence in the former of cordierite and the development of relatively large sillimanites which may form clusters". He thinks of this "sillimanite-gneiss" as essentially a sedimentary rock, affected by "a certain amount of permeation" from adjoining " epidiorite " ; and he gives two analyses, which certainly recall sediment rather than " epidiorite " (Table 1, ii, iii). Still he notes that " contact with the epidiorite is a gradual one and there is no hard and fast line between coarse sillimanite-biotite-gneiss, coarse biotite-gneiss, and biotite-rich epidiorite " (1940, p. 146).

From what we saw of the variety at Coire nam Muc, Johnstone and the writer feel that the term sillimanite-gneiss is unfortunate, for the matrix-rock does not have a gneissic appearance, but looks like a variable plutonic igneous product, sometimes a bit sheared. Apart from this the two views come very close in conveying an idea of chemical composition, for the one sees the rock as igneous with sedimentary contamination, while the other claims it as sediment with igneous contamination. It is only when we come to interpret its mode of emplacement that opinions differ strongly. Drever holds that, " in spite of the ' xenolithic ' character of the composite pelitic gneiss there is no justification in concluding that it behaved like a contaminated magma "—and it is important to remember that he has studied the subject intensively, whereas the writer has only seen the Coire nam Muc area. The main explanation that he offers of the difference between matrix and apparent xenoliths runs as follows :—During the sedimentation period, the bedded pelite was, he thinks, affected by slumping, so that it passed into a mush with enclosures of unbroken mud, etc. Then in ensuing ages the " epidiorite " magma arrived and furnished hot solutions which permeated the mush matrix, but " did not so effectively penetrate the enclosed relics " (1940, p. 165). Drever also thinks that there may have been a certain amount of tectonic breakage, before the magma arrived on the scene, which is a possibility that probably all would admit.

TABLE 1

Glen Scaddle " Epidiorite " and " Sillimanite-Gneiss "

	I	A	II	III
SiO_2	51·79	51·75	54·02	60·28
Al_2O_3	11·88	13·7	22·15	18·72
Fe_2O_3	0·67	9·5	0·77	0·30
FeO	10·66		6·64	6·03
MgO	8·51	9·2	2·22	2·68
CaO	7·92	8·5	1·54	2·44
Na_2O	2·37	2·0	2·14	3·43
K_2O	1·22	1·0	5·93	2·60
H_2O+	0·70		2·68	1·45
H_2O-	0·30		0·75	0·65
TiO_2	2·92	c.1·2	1·06	1·07
P_2O_5	0·64		tr.	tr.
MnO	0·19		0·16	0·15
CO_2	—		—	—
Total	99·77		100·06	99·80
Sp. Gr.	3·00		2·78	2·73

Analyses I, II, III by W. H. Herdsman, quoted from Drever (1940, pp. 153, 157).

I. " Epidiorite," Glen Scaddle.

A. Corresponding " average rock " of Devonian igneous series deduced from graphs, Fig. 38, p. 205.

II. " Sillimanite-gneiss " marginal to " epidiorite," Coire nam Muc.

III. " Sillimanite-gneiss," mixed from Coire nam Muc and Coire Dubh.

Let us pass on. Drever has made an important point in claiming that the limestone-pelite group, with its associated " epidiorite " which in its main outcrops he interprets as a mighty sill, structurally overlies all other rocks of the district (1940, pp. 149, 151). He bases largely on dips south-west of Bealach Choire nam Muc and again south-west of Coire Dubh. In both cases the dips are towards the north-east and bring on limestone, pelite and "epidiorite ". Admittedly the evidence of dips alone would place the limestone-pelite outcrop of Bealach Choire nam Muc on a lower structural horizon than that occupied at Coire Dubh ; but Drever, probably correctly, duplicates the structural succession by inserting a curving fault as north-eastern boundary of the Bealach outcrop of limestone, pelite and " epidiorite ". Such a fault suits Grant Wilson's mapping tolerably well, except that it is drawn across a digitate protrusion of " epidiorite " shown on Sheet 53 as extending towards Meall Dearg Choire nam Muc. Drever deals with this supposed protrusion (1940, fig. 3, p. 144) by treating it as " numerous epidiorite sills," companions of the main mass, intruded well below the level of the limestone-pelite group. It is unfortunate that Drever gives no direct evidence in his text to support his fault ; but in the figure just quoted he writes " fault and shatter belt " along part of its course, while Johnstone and the writer further north-west noted an appropriate feature at the foot of Meall an Tairbh.

Having made a good case for interpreting the main " epidiorite " outcrops in Coire nam Muc and Coire Dubh as parts of a single great sill intruded into the limestone-pelite group, Drever expands this hypothesis to include the extension of the Coire Dubh " epidiorite " outcrop right across Glen Scaddle to Druim Leathad nam Fias. As will appear presently (p. 124), Clough, the writer and Drever, all think that most of what has been mapped on Sheet 53 as Felspathised Sedimentary Gneiss corresponds roughly with a stratigraphical unit, distinct from the surrounding siliceous gneisses (a). If this be accepted, then Drever's conception of a single great sill can scarcely be doubted. Otherwise we have to rely mostly upon continued association of the " epidiorite " with the limestone-pelite group. Admittedly evidence for such association is meagre in the main Glen Scaddle " epidiorite " outcrop, except along 2½ miles of south-western margin through Coire Dubh ; but Drever has succeeded in finding " sillimanite-gneiss " on the eastern margin at Nat. Grid 009679 (1940, fig. 2, and N.E. corner, fig. 5, pp. 143, 147), and pure limestone a little in from the same margin at 009662 (1940, fig. 2).

In the Bealach Choire nam Muc belt, where the association of " epidiorite " with the limestone-pelite group is universal, the combined outcrop terminates north-westwards as soon as the external north-easterly dip, already noted along its south-west margin, swings round to become south-easterly (Drever 1940, fig. 3). This affords strong confirmation of Drever's view that here the " epidiorite," etc., in their whole breadth, overlie the " felspathized sedimentary gneisses " and the more external siliceous gneisses (a).

A similar termination of the main " epidiorite " outcrop is found north of Glen Scaddle, but marginal association with limestone or pelite has not been noted at this locality (1940, fig. 2). Beyond to the west, Sheet 53 shows a detached major outcrop of " epidiorite " crossing the end of Druim Leathad nam Fias. While this has not been reinvestigated, its position on the map suggests a reappearance of the Bealach Choire nam Muc band. If such be its true nature it would likely mean that Drever's curving fault bounding the latter is a low-angled thrust.

Returning to the main Glen Scaddle outcrop of " epidiorite," we get a further strong suggestion of synformal disposition on comparing the south-western and north-eastern margins, along both of which limestone-pelite association has been established. The external schists dip inwards on the south-west side whereas they stand almost vertical on the north-east. Altogether Drever's conception of a Glen Scaddle Synform striking north-west, and furnished with a core of the limestone-pelite group intruded by "epidiorite," seems well grounded on the local evidence. It receives further strong support from the probability, already indicated, that the siliceous gneisses (a) to the north-west structurally overlie the micaceous gneisses (b) of Meall nan Damh and Meall Mòr.

If we accept the Glen Scaddle Synform as a reality, then we must regard the siliceous gneisses (a), outcropping to the north in the "steep belt" of Cona Glen (p. 117), as rising from under the "felspathic sedimentary gneisses" and "epidiorite" of the Glen Scaddle complex. We must also expect these steep siliceous gneisses to connect antiformally with their continuation mapped by Wilson with north-easterly dip in the comparatively "flat belt" north of Cona Glen in Sgùrr an Iubhair. Johnstone and the writer hunted for direct evidence on this latter point, but found nothing conclusive. Well up the north-east face of Cona Glen, for a mile west of Allt a' Chnaip, the north-easterly dip recorded west of Sgùrr an Iubhair summit swings round to a little north or south of east with an inclination of about 50°. Also in the lower reaches of Allt a' Chnaip, 200 yd upstream from a farm-road bridge, there is a good exposure of an antiform pitching south-east. Both these observations favour the expected antiformal connexion ; but too little is seen in the critical valley bottom to inspire confidence. For instance, the observed antiform might near at hand be neutralised by an unobserved synform.

Drever considers that he has recognised a minor stratigraphical break at the base of the limestone-pelite group, but it is safer to regard the whole question of relationship as unsettled. He has further suggested that while the rocks below should be considered as Moines, the limestone-pelite group may be Dalradian (1940, p. 151). If comparison be restricted to the north-west side of the Great Glen Fault, it is tempting to look for the allies of the Ardgour limestone-pelite group in the varied assemblage of Shetland.

MAINLY IGNEOUS

The rocks entering into the Glen Scaddle Complex have been classified by Mr. Wilson (1901, p. 45) as follows :

(1) Epidiorite.
(2) Granulitic gneiss [felspathised sedimentary gneiss of Sheet 53].
(3) Diorite dykes, cutting granulitic gneiss and the surrounding gneissose flagstones [group (a) of this chapter].
(4) Grey basic dykes, now represented by hornblende-biotite-schists ; these cut (1), (2), (3) and the gneissose flagstones.
(5) Granulitic gneiss and Aplite (Porphyrite) dykes ; these cut (1), (2), (3), (4) and the gneissose flagstones.
(1916 edition)

The granulitic gneiss (2) of the above list may be taken first, as it is considered to be largely sedimentary—in the index of Sheet 53 it is shown as "felspathized sedimentary gneiss". The joint visit by Clough and the writer was undertaken largely to form an opinion as to its nature, and as to the propriety of separating it on the forthcoming one-inch map. Clough approached the difficult problem with intimate experience of what are mapped at Glenelg (Sheet 71) as Moines "permeated by pegmatites"—usually classed as injection products. His conclusion was that Wilson's mapping supplied a valuable approximation, that the rock should be separately shown on Sheet 53 with the title quoted above, and that the writer should insert the following paragraph in the 1916 memoir.

The more important epidiorite outcrops are surrounded by a felspathised zone of granulitic gneiss (S 8235) from 150 to 300 yds. in breadth (Wilson *in* Sum. Prog. 1899, p. 40). A typical exposure of this felspathised zone is afforded by the river Scaddle near a small waterfall, half a mile above the junction of the river with the Cona. It is a fine-grained, banded rock in which close examination reveals a most unusual proportion of fairly idiomorphic felspar. The felspathic material appears to have been superimposed upon a thinly bedded, fairly pelitic sediment, considerably more pelitic, for instance, than that which gives rise to the siliceous gneisses occurring farther downstream. The felspathised rock has suffered very extensive shearing after the consolidation of the introduced felspathic material ; in fact, it is quite possible that all the movement chronicled in the rocks of the district followed the epoch of intrusion, but this has not been proved for certain. (1916 edition)

Drever apparently considers the so-called felpathised sedimentary gneisses as mere sedimentary variants of the more siliceous gneisses, without significant late introduction of felspathic substance. The felspars, he finds, are orthoclase and oligoclase in any proportion (1940, p. 162). Interbanding of more or less felspathic types he attributes to interbedding. Contact with his " sillimanite-gneiss " (p. 121) he describes as gradual. On the whole, he says, the felspathic granulite becomes coarser on approach to the main " epidiorite," but its most interesting feature in this position is that it contains fragments, which though distinguishable, are still closely similar to itself. This reminds him of how the " sillimanite-gneiss " commonly includes fragments of sillimanite-hornfels (1940, pp. 147, 149).

Drever finds complex folding in the felspathic zone away from immediate proximity of the " epidiorite ". " Much, if not all, of this folding " he regards as " clearly due to slumping " (1940, p. 149). He has also noted that the part of the felspathic granulite adjacent to, or interbanded with, the " sillimanite-gneiss " holds fragments of banded heavy-mineral sediment, rich in sphene and iron ore. These, he says, " were formed almost undoubtedly by original slumping " (1940, p. 163) ; but it may be well to suspend judgement. Drever further realises that quartzo-felspathic veins traverse some of the fragments in a manner suggesting that mobile granitic material existed in the granulite during its crystallisation.

On comparing Clough's and Drever's interpretations of the felspathic gneiss or granulite, it will be noted that they agree in holding that the felspathic zone roughly corresponds with a group that originally differed from the underlying more siliceous Moines. Clough was prepared to believe that there had been considerable chemical modification by introduced felspar constituents—he probably was quite doubtful as to how much. Drever seems to have thought that there was little or no reinforcement from outside.

The difference may be less than appears at first sight, for Clough was one who thought auto-injection an important possibility. Thus, speaking of the Moines " permeated by pegmatites " at Glenelg, he notes that they occur in regions of high metamorphism, and continues : " As the pegmatite patches are usually edged with a sheath of rock which is much richer in biotite than the rock further away, it is suggested that they represent segregations derived from the immediately adjoining rock, rather than injections of foreign materials. This suggestion is, perhaps, somewhat strengthened by the frequent occurrence of small pegmatitic spots or *augen*, varying in size from a hazel nut to a duck's egg, which appear to be quite isolated in the rock " (1910, p. 83). Most authors, however, think that the injection complexes of Glenelg, etc., have received a large proportion of their quartzo-felspathic material from a distance. On the other hand, the Glen Scaddle felspathic granulites are not normal injected products. Their felspar is distributed, rather than concentrated. " It is a point of importance," Drever says (1940, p. 149), " that pegmatite veins are not a prominent feature though occurring in certain places " ; and he categorically states that the felspathic granulite " is not confined to the belt which surrounds the epidiorite masses, but occurs again in thick and extensive beds farther up Glen Gour ".

The writer agrees with Clough and Drever that the rocks of the felspathic zone have not been developed through alteration of siliceous gneisses of group (a) ; and he is also inclined to favour Drever's view that their peculiar chemical composition is an original sedimentary feature.

Let us now turn back to the " epidiorite," item (1) in the table on p. 124 :

> 1. The main epidiorite mass [of Glen Scaddle] is of somewhat irregular shape. It stretches north-westwards from Loch Linnhe, with one important interruption, for about half a dozen miles, and it has a maximum breadth of rather less than three miles. In texture the epidiorite varies from coarse to medium, and is generally of a dark grey colour, which, at several points not far from the margin, gives place to red. It appears to have been originally a diorite and, to a large extent, it has escaped conspicuous alteration. It is often massive or imperfectly foliated (S 8233), but in many instances it is in a thoroughly gneissose condition. Mr. Wilson (Sum. Prog. 1899, pp. 40-2) found that the foliation commonly strikes between 15° and 25° west of north, and that it is parallel to the foliation of the surrounding sedimentary gneisses.
>
> There are many isolated masses of epidiorite in connection with the Glen Scaddle Complex, and perhaps the numberless lenticles of hornblende-schist found intruded among the sedimentary gneisses of the Glen Tarbert district belong to the same suite. The small mass of epidiorite by the roadside at Gearradh, between Glen Gour and Glen Tarbert, consists of dark foliated rock resembling that of which the lenticles are composed. The Inversanda outcrop at the mouth of Glen Tarbert is a grey dioritic rock, much shattered owing to the proximity of the Loch Linnhe fault, but with very little foliation. The detached outcrops between Glen Gour and Glen Scaddle are in every way similar to the main mass of Glen Scaddle. (1916 edition)

The structural significance of the association of the Glen Scaddle " epidiorite " with limestone and pelite, especially well seen at Bealach Choire nam Muc and Coire Dubh, has already been discussed somewhat fully, under heading (d). Here we may add that the minor " epidiorite " outcrop, which north of Inversanda Bay forms a hill called Creag nam Bà on the six-inch map, has yielded Drever calc-silicate-hornfels of a type represented at both the localities just mentioned. It would therefore appear possible that the major Glen Scaddle " epidiorite " sill has been folded down to ground-level at Inversanda.

Drever has supplied an analysis from Glen Scaddle, quoted on p. 122. Except that it has quite unusually high TiO_2, it agrees wonderfully closely with Analysis A placed alongside for comparison. This latter gives the composition expected of an " average rock " of like silica percentage in the Devonian suite of chapter xvii. One notices especially the low alumina, high magnesia and rather high potash. Drever says : " The essential minerals are the two pyroxenes (which are present in about equal amount) and plagioclase. The amount of hornblende and biotite is variable. Ilmenite, apatite and interstitial quartz are prominent minor constituents, and microperthite found irregularly replacing plagioclase or forming antiperthitic structure is very often present but in variable amount. Myrmekite may be found associated with microperthite. A specimen from Coire nam Muc has fresh pyroxenes with considerable biotite and microperthite " (1940, p. 152). Such descriptions suggest the augite-diorites and monzonites of the Devonian suite, and one is not surprised to hear of minor outcrops of appinite and peridotite.

The question naturally arises as to whether the Glen Scaddle " epidiorite " may not belong to this Devonian suite—which, it is thought, may have started to intrude in pre-Devonian times. Perhaps an answer will eventually come based on physical rather than geological research. Meanwhile it must be remembered that a monzonitic diorite in Colonsay (60 miles to the south-west) has been shown by Wright (1908 ; Wright and Bailey 1911, chaps. v, vii) to be intermediate in date between two cleavage-making movements that have folded the local Torridonian. This Colonsay augite-diorite is associated with kentallenite and appinitic hornblendite, so that its place in the Devonian suite is admitted by all.

The following comments concern Items (3) to (5) of the table on p. 124 :

> " 3. In Cona Glen the river-section for a distance of half a mile, below the keeper's house, exposes numerous foliated diorite dykes from 2 to 30 ft broad which traverse the flagstones. Some of these in turn are cut by small dykes of granulitic gneiss and veins of aplite. To the south-east of Glen Scaddle several broad diorite dykes cut both the acid gneiss [Item 2, p. 124] and the flagstones [Group a, p. 117].
>
> " 4. Eleven foliated grey basic dykes, now represented by hornblende-biotite-schists, were mapped last year on the southern slopes of Glen Scaddle (S 8236)[1]. They intersect both the epidiorite and the granulitic gneiss [Item 2], while two in Cona Glen traverse the flagstones [Group a].
>
> " 5. On the south side of Glen Scaddle the epidiorite is cut by a large number of dykes and veins of foliated granulitic gneiss (S 8234).[2] Similar dykes have also been mapped to the south-east of Corrlarach in Cona Glen, intersecting the flagstones " [Group a] (Wilson *in* Sum. Prog. 1901, p. 46). These aplite veins are often more foliated than the surrounding epidiorite (Wilson *in* Sum. Prog. 1899, p. 41). Like the Scourie dykes of the North-West Highlands these veins have been specially picked out by shearing movement. More than this, the epidiorite was evidently foliated, in some cases, at least, before the introduction of the aplite veins. The latter are frequently sheared more or less parallel with their length in marked discordance with the general direction of the older and frequently much ruder foliation developed in the surrounding epidiorite. The shearing of individual veins has extended for a short distance into the epidiorite, and the older foliation of the latter has sometimes been dragged sharply round into parallelism with the newer structure of the adjacent vein. These phenomena of intermittent intrusion and foliation recall the sequence which has been worked out in the Lizard Complex in Cornwall (Flett 1912, pp. 22-25).
>
> Just as there are abundant lenticles and sills of hornblende-schist, the connection of which with the Glen Scaddle Complex is uncertain, so too, there are abundant pegmatite veins cutting the surrounding sedimentary gneisses, which can only be assigned to this complex with a certain amount of hesitation. These veins are, some of them, massive, some foliated, and the same vein may be massive in one part of its course and foliated in another. One pegmatite may often be seen cutting another. Small sills of hornblende-schist intruded into quartz-granulite [Group a] and cut by pegmatite may be seen in the crags north of Loch nan Gabhar. In this case the igneous rocks may be referred with high probability to the Glen Scaddle Complex which is represented in force a little farther north-east. (1916 edition)

Drever points out that sheets of " epidiorite " and hornblende-schist of variable dimensions occur both in the " felspathised sedimentary gneisses " of Sheet 53 and in Wilson's flagstones (Group a) alongside ; and that they are sometimes so numerous as to constitute a basic injection complex (1940, p. 149). He also gives details of appinite occurring as sheet-like masses in the former (1940, p. 145).

The 1916 edition includes a short account of the Sgùrr Dhomnuill augen-gneiss, which it says has a very irregular margin against adjacent schists, in part due to injection. Later work ascribes the gneiss to injection phenomena (p. 116). The statement by Peach and Wilson that " it is seen to cut some small masses of epidiorite and hornblende-schist, but in turn is pierced by later dykes of that material " (Sum. Prog. 1904, p. 68) presumably still holds.

Small portions of the Strontian Granodiorite Complex projecting into Sheet 53 from the west, and certain red granite outcrops along Loch Linnhe will be dealt with shortly in chapter xv. The latter are accompanied by felspathised border rocks, which are locally responsible for outcrops included on Sheet 53 under the title " felspathised sedimentary gneisses ". E. B. B.

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[1] Teall says this rock differs from ordinary hornblende-schist in that the felspar tends to be lathy and zoned. He is " inclined to regard it as igneous " (Sum. Prog. 1899, p. 141).

[2] T. R. M. Lawrie says this rock is identical with certain fine-grained felsparphyric sheets recently reported by the West Highland Unit from near Loch Shiel and Loch Arkaig, west and north of Sheet 53. These are described as " possibly of trondhjemitic affinities " and occasionally foliated but younger than the regional pegmatites (Sum. Prog. 1953, p. 36).

CHAPTER X

ROCKS OF LOWER OLD RED SANDSTONE AGE

INTRODUCTION

Rocks which accumulated at the surface during, in all probability, Lower Old Red Sandstone times are preserved in the Glen Coe district and also, less extensively, at Ben Nevis. They are represented in both places mainly by lavas and agglomerates, with stratified rocks forming a very small proportion of the whole succession.

Plant-remains, including indeterminate stems and *Pachytheca fasciculata* Kidston and Lang, have been found in basal sediments at Glen Coe ; but they have proved difficult to date precisely (p. 145). Still, there are such close similarities between the lavas of Glen Coe and Ben Nevis and those of Lorne, only 15 miles to the south-west (Fig. 18), that it seems safe to regard the three suites as broadly contemporaneous ; and the sediments associated with the Lorne volcanic series have yielded fishes, a eurypterid and millipedes which are assigned by experts to the Lower Old Red Sandstone formation (for summary of the evidence with full references, see Bailey 1925, p.31).

The volcanic and sedimentary rocks rest with a violent discordance upon an old land surface sculptured in the Highland Schists, and now partially brought to light again by denudation. The deformation to which they have been subjected is mainly due to faulting. Folding, though sometimes sufficiently intense to produce inversion, is a local phenomenon, a phase of the faulting, not part of an extended system of crustal buckling ; and there is no trace of cleavage.

The sedimentary rocks, consisting of red, grey and black shales, compact grits and conglomerates, are greatly indurated, whilst the volcanic rocks show various changes, due to weathering and the percolation of underground waters. Both too have suffered from contact-alteration in the vicinity of a northward extension of the Cruachan Pluton.

Amongst the volcanic rocks hornblende- and biotite-andesites are the only types of lava met with on Ben Nevis ; whilst in Glen Coe basalt, pyroxene-andesite, hornblende-andesite and rhyolite, together with transitional varieties, are all represented.

The internal structure of the volcanic pile in Glen Coe (Fig. 21) leads us to believe that this district was supplied from more than one source, situated in the immediate vicinity, though it is impossible now to point to the site of the volcanic vents. It is probable, however, that the lavas and sediments of Glen Coe may originally have been confluent with those of Lorne, on the one hand, and of Ben Nevis, on the other. A small crag of conglomerate made up of well-rounded boulders of quartzite occurs on the hilltop north of Gleann Seileach, near Onich. It is probably *in situ* and of Lower Old Red Sandstone age, and, if these assumptions are correct, its position about equidistant from Glen Coe and Ben Nevis serves as a connecting link between the two. Fragments of similar conglomerate have also been found just beyond the eastern border of the map involved in a landslip at the southern foot of Stob Choire Claurigh (Sheet 54, Geol.) at the head of Allt Coire Rath.

In this connection it should be noted that the Old Red Sandstone rocks of Glen Coe (Fig. 19) and Ben Nevis (Fig. 31) owe their preservation in large

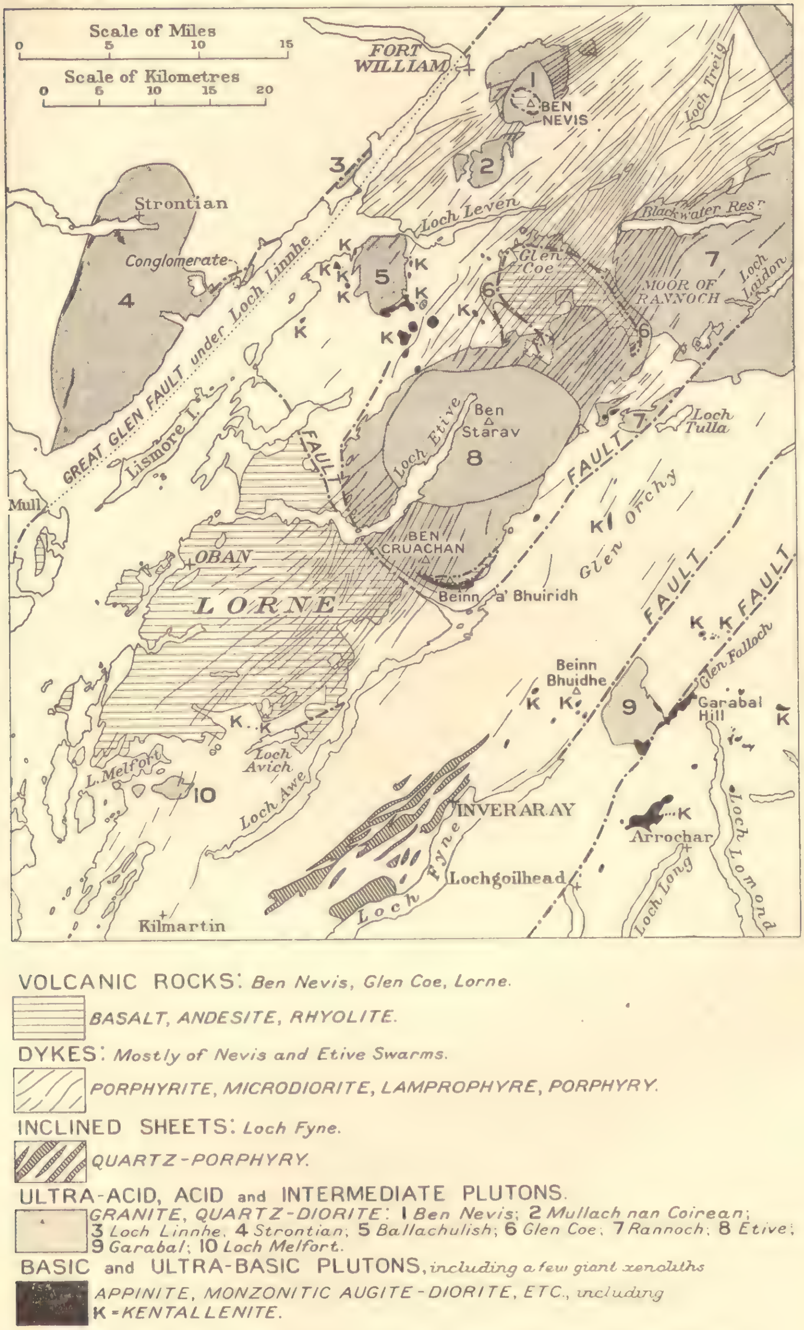
Scale of Miles
0 5 10 15
Scale of Kilometres
0 5 10 15 20
FORT WILLIAM
1
BEN NEVIS
Loch Treig
2
3
Strontian
Loch Leven
Blackwater Resr
Conglomerate
K
5
Glen Coe
7
Loch Laidon
MOOR OF RANNOCH
4
GREAT GLEN FAULT under Loch Linnhe
6
Lismore I.
Ben Starav
Loch Etive
8
FAULT
Loch Tulla
Mull
BEN CRUACHAN
Glen Orchy
OBAN
LORNE
Beinn a' Bhuiridh
FAULT
Beinn Bhuidhe
Glen Falloch
9
Garabal Hill
Loch Avich
L. Melfort
10
Loch Awe
INVERARAY
Arrochar
Loch Lomond
Loch Fyne
Lochgoilhead
Loch Long
Kilmartin
VOLCANIC ROCKS: Ben Nevis, Glen Coe, Lorne.
▤ BASALT, ANDESITE, RHYOLITE.
DYKES: Mostly of Nevis and Etive Swarms.
▨ PORPHYRITE, MICRODIORITE, LAMPROPHYRE, PORPHYRY.
INCLINED SHEETS: Loch Fyne.
▨ QUARTZ-PORPHYRY.
ULTRA-ACID, ACID and INTERMEDIATE PLUTONS.
□ GRANITE, QUARTZ-DIORITE: 1 Ben Nevis; 2 Mullach nan Coirean; 3 Loch Linnhe. 4 Strontian; 5 Ballachulish; 6 Glen Coe; 7 Rannoch; 8 Etive; 9 Garabal; 10 Loch Melfort.
BASIC and ULTRA-BASIC PLUTONS, including a few giant xenoliths
■ APPINITE, MONZONITIC AUGITE-DIORITE, ETC., including K = KENTALLENITE.

FIG. 18. Map of igneous rocks of South-West Highlands referred to Lower Old Red Sandstone Period

measure to faulting, by which they were let down relatively some thousands of feet. It will be shown that the subsidence of the Glen Coe fault-block was accompanied by the uprise of igneous magma, which consolidated about the downthrown mass. Subsequent denudation has revealed the consolidated magma as an almost continuous ring of " fault-intrusion " surrounding a " cauldron-subsidence ". At Ben Nevis there was probably a similar uprise of fault-intrusion, but erosion has cut down to a lower level, and reveals instead what we take to be magma (now " granite ") retained in the reservoir into which cauldron-subsidence carried down a portion of the roof.

Chapter xi, which follows, deals with the volcanic and sedimentary rocks of Glen Coe from the point of view of their local variations and their relations to the floor of crystalline schists upon which they accumulated. Chapter xii also concerns Glen Coe, but concentrates attention upon the cauldron-subsidence and the associated fault-intrusions (6, Fig. 18). Chapter xiii treats of the great " granitic " complex of Etive (8, Fig. 18), of which the Glen Coe Fault-Intrusions may be regarded as early northern offshoots. Chapter xiv describes the lavas, sediments and plutonic rocks of Ben Nevis (1, Fig. 18). Chapter xv follows with an account of several plutonic masses which are with considerable confidence ascribed to the same general period as those of Glen Coe, Glen Etive and Ben Nevis. Chapter xvi treats of minor intrusions of probable Lower Old Red Sandstone age. These include some relatively early, widely distributed sheets of lamprophyre ; but the great majority are N.E. dykes definitely associated with either the Etive or the Ben Nevis plutonic foci. Petrological details are throughout reserved for chapters xvii and xviii. In reading the chapters dealing with field-relations it is well to bear in mind that " granite " is used in an extremely broad sense to include both granite and quartz-diorite.

The evidence that all the intrusions mentioned above are not of later date than the lower Old Red Sandstone period rests upon the fact that similar dykes and plutonic masses, in the East Highlands, are always earlier than the widespread Orcadian or Middle Old Red Sandstone of that district.

If next we seek a lower limit for the age of these intrusions, we note that some of them are certainly younger than the lavas of Glen Coe and Ben Nevis, which we have seen above may safely be placed in the long period of the Lower Old Red Sandstone. Thus :

(1) The Fault-Intrusion of Glen Coe, the " Granite " Complex of Etive, and the accompanying swarm of dykes can be demonstrated to be later than the lavas of Glen Coe.

(2) The Inner " Granite " of Ben Nevis and a few individuals of the dyke-swarm of that mountain are equally clearly later than the lavas of Ben Nevis.

To proceed. The age-relation of the Outer " Granite " and of most of the dykes of Ben Nevis to the lavas cannot be settled by examination of contacts ; but the analogy of the Outer " Granite " of Ben Nevis to the Outer or Cruachan " Granite " of the Etive Complex, and of the dyke-swarm of Ben Nevis to the dyke-swarm of Etive (Fig. 18), leaves no real doubt as to the Lower Old Red Sandstone age of the entire Ben Nevis Complex and its attendant dykes.

For the rest of the " granites," again no direct field evidence is available ; but we rely upon the close petrographical affinity, which seems to link them with the intrusions of Etive, Glen Coe and Ben Nevis into a single great suite. There is, however, one main cause for hesitation in pressing this conclusion : in Lorne and also in Glen Coe, " granite " boulders *of types similar to those of proved Lower Old Red Sandstone age*, are locally abundant in the basement conglomerates of the great volcanic series. Some geologists, notably G. Barrow, attach considerable weight to these " granite " boulders, regarding them as evidence in favour of a period of " granitic " intrusion *much* earlier than that of Lower Old Red Sandstone times. To the writers, however, this argument does not seem very strong, since, in Skye, Mull, and Arran, Tertiary granophyres and gabbros are abundantly represented in Tertiary agglomerates. The answer, already anticipated by A. Harker, was supplied in Mull where certain explosive vents show early Tertiary granophyre and gabbro in contact with later Tertiary agglomerate. Now, in Lorne and Glen Coe, to return to the district under consideration, no natural base of the Lower Old Red Sandstone is known, and the conglomerates which contain the " granite " boulders, often contain also an overwhelming proportion of volcanic rocks, which, like the " granites," are of types common in the Old Red Sandstone suite. It seems reasonable then to suppose that such basement conglomerates may have formed at a comparatively late stage in the vulcanicity of the district, when " granites," of the same general age as the lavas, had already become available, as a source for boulders, through the agency of explosion or even of erosion. A likely source for some of the boulders is the Moor of Rannoch Pluton (7, Fig. 18), which Grabham has shown to be older than the Fault-Intrusion of Glen Coe. H. K., H. B. M., E. B. B.

While it may be taken as almost certain that the major " granite " plutons of Sheet 53 belong to a single great suite which flourished in Lower Old Red Sandstone times, it remains quite possible that this suite, even in the West Highlands, had its beginning in the late Silurian. In the east, near the Highland Border towards Stonehaven, there are similar " granite " plutons which appear to have yielded many boulders to neighbouring Downtonian conglomerates. Accordingly the " granites " concerned, both in the west and in the east, are often called " Newer " or " Caledonian " to avoid more specific dating.

Chapter xv furnishes notes on the field relations of certain small basic and ultrabasic plutons, including such characteristic types as appinite, monzonitic augite-diorite and kentallenite. These are shown black in Fig. 18 where their grouping about the Ballachulish and Garabal Hill Plutons (5, 9, Fig. 18) may be taken to indicate a common origin. Boulders resembling much decomposed kentallenite have been noted by Maufe in a Glen Coe conglomerate (p. 144); so that in this matter the basic and ultrabasic rocks are on a par with their intermediate and acid associates. For further suggestions concerning age we must go to the island of Colonsay, 40 miles south-west of Sheet 53. Here and here alone outside Fig. 18 do we find an additional example of the associated basic and ultrabasic types listed above ; and here, in Colonsay, we find that some at least were intruded during an interval between two episodes of Caledonian movement, both strong enough to cleave Lower Torridonian sediments that serve as country-rock. The earlier of these two movements was the more powerful, and was accompanied locally by a metamorphism that developed minute biotites and hornblendes in some of the sediments (Wright 1908 ; Wright and Bailey 1911, p.36).

The remoteness of the Colonsay outcrops may possibly be due to displacement along the Great Glen Fault (chapter xxi). If so, the fault passes south-east of Colonsay, not north-west as shown in Fig. 40. This is an alternative which the present writer favours on quite other grounds. E. B. B.

CHAPTER XI

ROCKS OF LOWER OLD RED SANDSTONE AGE

VOLCANIC SERIES OF GLEN COE

THE volcanic rocks of the Glen Coe district occupy a roughly oval area, situated in the south-east corner of the map and measuring nine miles in length by five in breadth (Fig. 19). They form the centre of the mountainous district about Glen Coe and the upper part of Glen Etive, giving rise to about a dozen peaks over 3000 feet in altitude. On the north side of Glen Coe they constitute the jagged

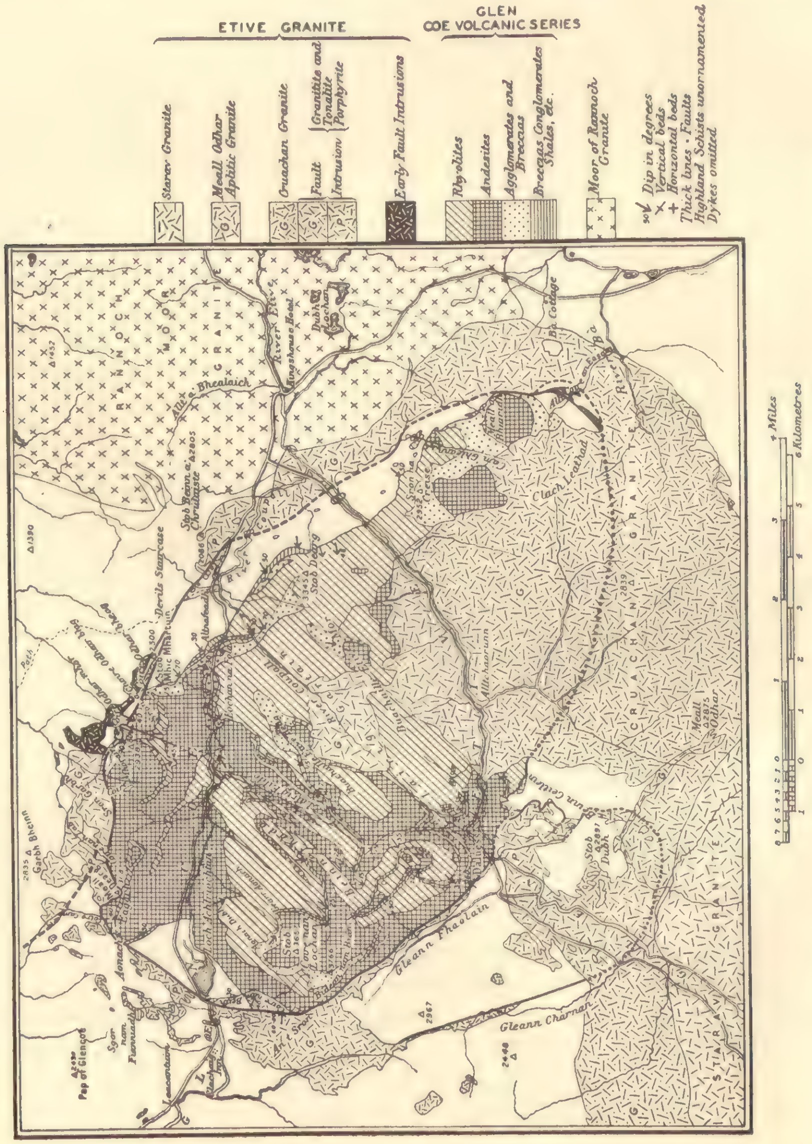

FIG. 19. Map of the Cauldron-Subsidence of Glen Coe and associated igneous phenomena
For new road see Fig. 22

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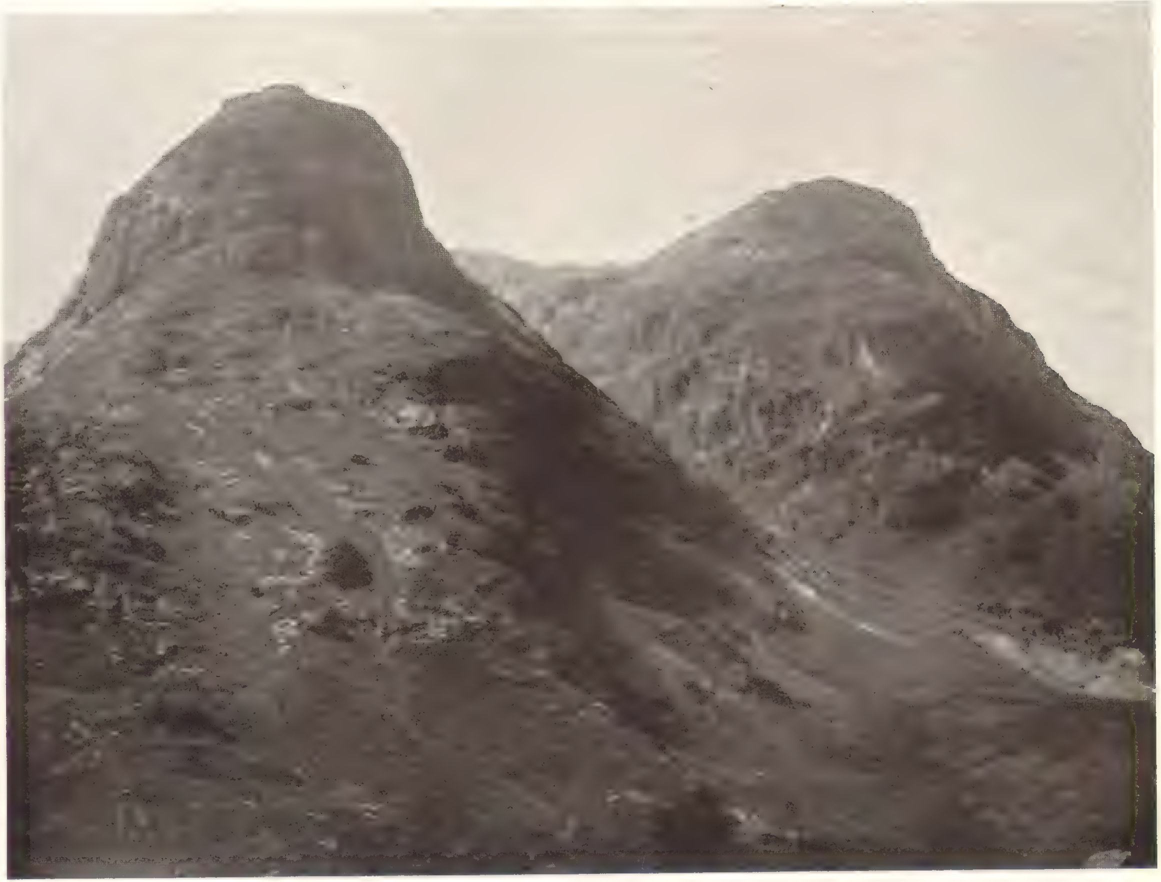


GEÀRR AONACH AND AONACH DUBH : GLEN COE " SISTERS "
Largely rhyolite lavas

ridge of Aonach Eagach, whence a south-easterly dip brings them down into the central portion of the glen. On the south side they reach a height of 3766 feet in Bidean nam Bian (Fig. 20), and form the northerly spurs of this hill, which are known as the " Three Sisters of Glen Coe " (Aonach Dubh, Geàrr Aonach, and Beinn Fhada, Pl. VI). Thence they extend eastwards into the two " Herdsmen of Etive " (Buachaille Etive Beag and Buachaille Etive Mòr, of which latter Stob Dearg is the main peak, Pl. VIII, p. 146). South of this they cross Glen Etive, to build the northern and eastern ridges of Clach Leathad and the shoulder of Beinn Ceitlein above Dalness.

The area thus defined is surrounded for four-fifths of its circumference by a fault which throws down the volcanic rocks and the underlying schists some thousands of feet. On the south side, where the fault is wanting for a distance of 4 to 5 miles, the volcanic rocks have been invaded by a lobe of the Cruachan Pluton which has penetrated into the heart of the volcanic region.

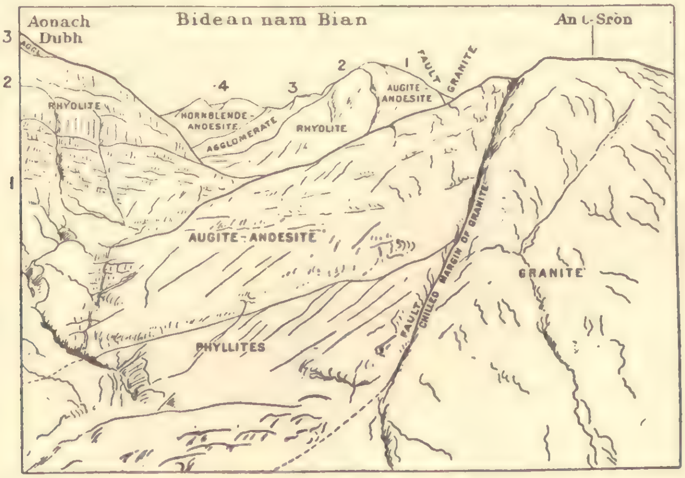


FIG. 20. View of Boundary-Fault of the Cauldron-Subsidence of Glen Coe as exposed in An t-Sròn

A. STANDARD SEQUENCE : LOCH ACHTRIOCHTAN TO BUACHAILLE ETIVE BEAG

A traverse up Coire nam Beith, between An t-Sròn and Aonach Dubh, to the top of Bidean nam Bian, and thence to the southern summit of Beinn Fhada, furnishes the best introduction to the study of the volcanic series (Fig. 20 and Sections II, IV, of Fig. 21). A condensed account will suffice for most readers, while further detail is given elsewhere (Clough, Maufe and Bailey 1909, p.615).

The full sequence encountered is as follows, in descending order :

		ft
7. Andesites and Rhyolites	about	300
6. Shales and Grits	„	50
5. Rhyolite	„	250
4. Hornblende-Andesites	„	900
3. Agglomerate and Shale	„	250
2. Rhyolites	„	450
1. Augite-Andesites and Basalts	„	1500
	Total	3700

Group 1. Augite-Andesites and Basalts.—About 17 flows of augite-andesite and basalt occur in Group 1, and are well exhibited in the precipitous lower crags of Aonach Dubh. In the stream of Coire nam Beith (Fig. 20) they are separated from the underlying phyllites by a couple of feet of purple sandy shale containing flakes of phyllite.

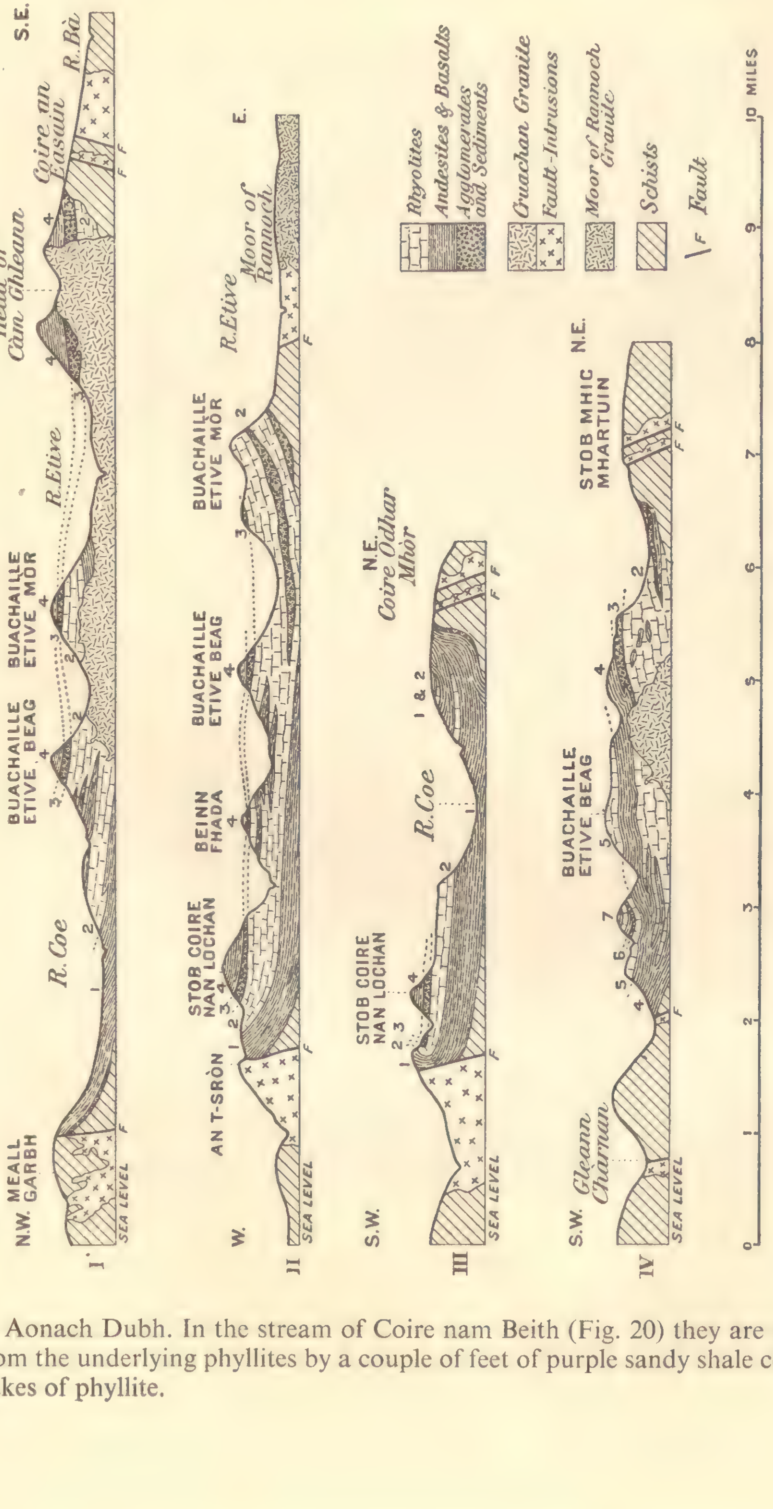


FIG. 21. Sections across the Cauldron-Subsidence of Glen Coe
The numbers 1-7 refer to groups discussed in the text

(At Coire an Easain the boundary-faults incline outwards to S. E., not inwards as shown above)

The lavas closely resemble the more basic flows constituting the greater portion of the Lorne Series. They are dark grey, almost black when fresh, and become purple, reddish and greenish on decomposition. Small black phenocrysts of augite and red pseudomorphs after olivine can often be detected.

They are only sparingly amygdaloidal, and their vesicles are filled with calcite, agate, red jasper, and sometimes epidote. They are often much brecciated, with red shale bedded into the interstices between the blocks. Breccias of this type must not be confounded with agglomerates. Good examples are exposed near the summit of the group in Coire nam Beith and between the Coe and the road 400 yards south of east of Achtriochtan farm (Fig. 22). Occasional beds of shale and grit intervene among the lavas, as may be seen to advantage 200 yards east of the upper fall in Coire nam Beith.

The upper surfaces of some of the flows are reddened in a manner suggesting contemporaneous weathering.

The lavas of Group 1 outcrop without material change south-eastwards along the Boundary-Fault from An t-Sròn to Dalness in Glen Etive ; and in the other direction they cross the Coe in force between Achtriochtan farm and the Queen's Cairn (Fig. 22), as will be described in the following section.

Group 2. Rhyolites.—There are three rhyolite lavas in Aonach Dubh of Fig. 20, each about 150 feet thick. They all show fluxion structure, and the uppermost flow-brecciation in addition.

The local variations of Group 2, represented by rhyolites alone in the type section, are extremely interesting. Traced into the western peak of Bidean nam Bian, where the rocks stand on end near the Boundary-Fault (Fig. 20), the rhyolites die out entirely. Followed to the east, on the other hand, from Aonach Dubh through the other two " Sisters of Glencoe " (Geàrr Aonach and Beinn Fhada), the group expands, and in the last-named, and also in the opposite slopes of Buachaille Etive Beag, it includes a very large proportion of andesite flows (Section II, Fig. 21). Among these latter both augite- and hornblende-andesites occur, and their intercalation with the rhyolites, which they more or less replace in the succession, can clearly be traced in Beinn Fhada. The thickness of the group in this locality must be about 2000 feet.

Farther east again, the andesite-lavas of Group 2 disappear even more suddenly than they came. Not one of them extends round the northern face of Buachaille Etive Beag, for this consists entirely of rhyolite.

Group 3. Agglomerates.—The next group in Fig. 20 is a mass of agglomerate made up of blocks of augite-andesite and rhyolite and underlain by about 20 feet of greenish sandy shale.

This agglomerate marks an important period during which few if any lavas were erupted. The accumulation is of variable character, and often gives place to green shales and grits. The latter are well bedded and show that the structure of the central portion of the Glen Coe area is characterised by a prevalent southerly dip of varying amount. The fine-grained sediments are 100 feet thick in Allt Coire Gabhail. In the western slope of Beinn Fhada they are much thinner, and in the eastern slopes are lost sight of. They reappear, however, at the head of Allt Lairig Eilde, and connect north-eastwards with agglomerate, just as in the type section of Stob Coire nan Lochan.

Group 4. Hornblende-Andesites.—The hornblende-andesites of Bidean nam Bian weather with a pale crust, though dark greenish-grey to black on a fractured

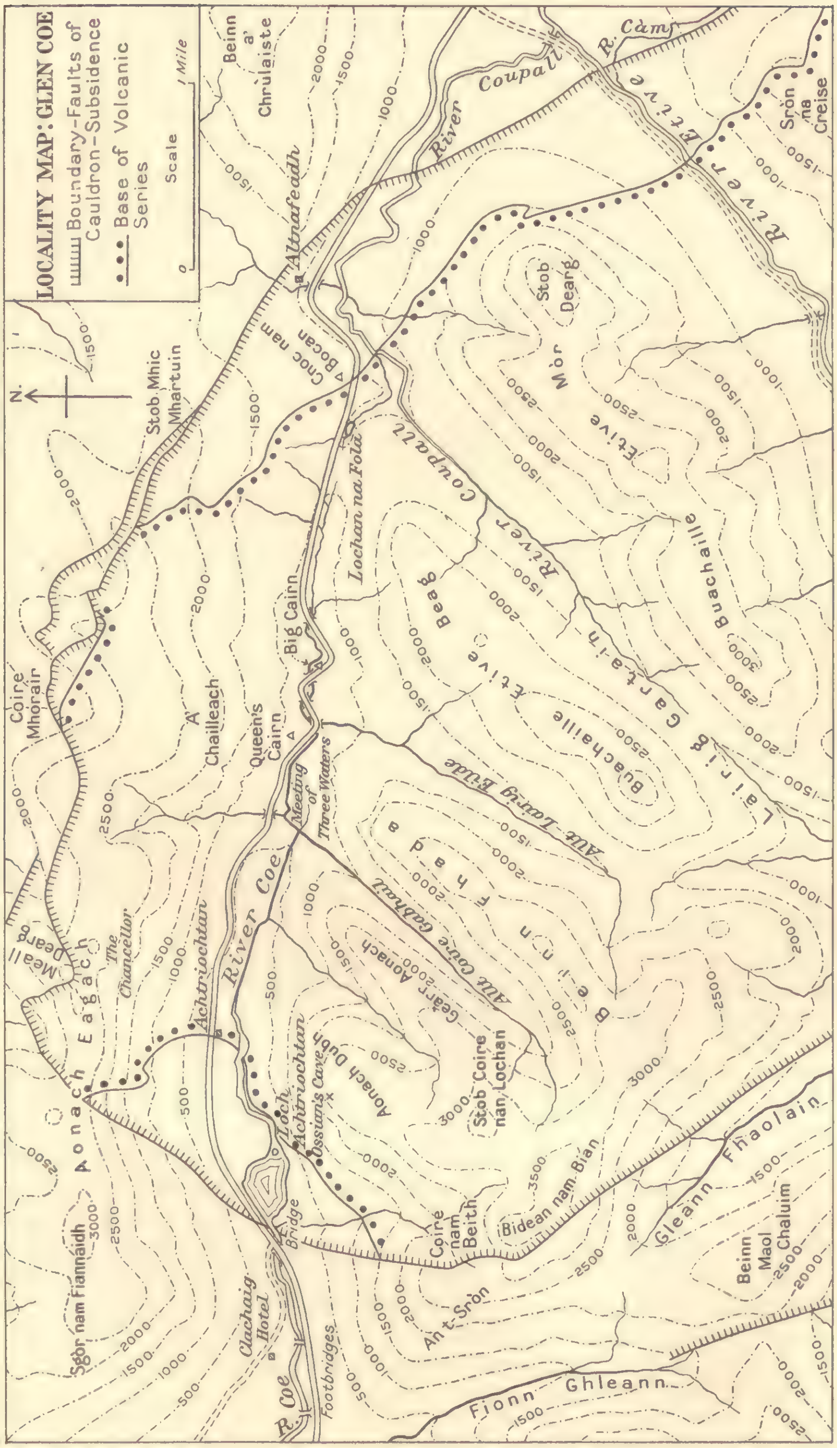


FIG. 22. Locality map : Glen Coe

surface. They carry small but fairly conspicuous phenocrysts of plagioclase felspar and hornblende in a compact base, which often exhibits flow-banding.

This is the youngest division included in Fig. 20. Its outcrop reaches continuously from Stob Coire nan Lochan to Buachaille Etive Beag.

Group 5. Rhyolite.—A black vitreous rhyolite, rich in phenocrysts of felspar, succeeds the hornblende-andesites of Bidean nam Bian. Though a thick mass it may be a single flow. It encloses numerous xenoliths of rhyolite and hornblende-andesite, and occasional pieces of quartzose schist.

Rhyolites in this position extend along Beinn Fhada, and also form an outlier on Buachaille Etive Beag ; and they probably enter into the contact-altered mass forming the southern end of Buachaille Etive Mòr. Their base dips at moderately high angles towards the south.

Group 6. Shales and Grits.—Well stratified greenish-grey shales and grits now interrupt the volcanic sequence. They vary considerably in thickness and seem to have collected on a lake bottom. Their outcrop, with that of the following Group 7, is limited to the southern shoulder of Beinn Fhada.

Group 7. Andesites and Rhyolites.—The topmost group preserved consists of rhyolites and hornblende-andesites accumulated in very irregular fashion (Section IV, Fig. 21, p. 134). H. K., H. B. M.

B. ROAD EXCURSION : LOCH ACHTRIOCHTAN TO ALTNAFEADH

In the locality map (Fig. 22) the new Glen Coe road is drawn with firm boundaries, while the old road is only shown west of Loch Achtriochtan. The following account of roadside geology extends eastwards from this loch to Altnafeadh, and includes other interests besides those directly concerned with the volcanic rocks. In a previous excursion starting from the mouth of the glen we reached the Boundary-Fault of the Cauldron-Subsidence of Glen Coe (p. 77), and described it as seen in An t-Sròn (Fig. 20) and in the River Coe. Let us start here and work our way inwards into the cauldron, that is towards the left in our picture.

The groups of lava and agglomerate numbered in Fig. 20 will be referred to constantly as we proceed ; but the standard account of their development along the deeply-indented precipitous southern slopes of the glen has already been given in the preceeding section.

The underlying phyllites, though well exposed in Fig. 20, are in most of their outcrop south of the road covered by the water and alluvium of Loch Achtriochtan. This, however, does not prevent the eye from following, just south of the Coe, their approximate junction with augite-andesites and basalts of Group 1 ; though, in the broad bottom of the glen north of the river, erosion has removed for a space all trace of escarpment.

North of the road, the lavas of Group 1 soon reassert their position in the topography and furnish a conspicuous cliff running obliquely up the hill-slope to meet the Boundary-Fault midway along the craggy summit ridge of Aonach Eagach (Jagged Ridge). Close to the fault the lavas are tilted vertical, but at a little distance they dip away from it with a regular, fairly steep, south-easterly inclination.

Proceeding east along the road one soon comes to the furthest north point of Loch Achtriochtan, beyond which its shoreline leaves the road turning abruptly to the south-east. Here, on the north side of the road, one can hammer convenient exposures of the little-altered phyllite (Leven Schists). Here too, looking north-eastwards up the steep face of the glen, one can realise that the phyllite tract terminates within a distance of about a mile. Rock exposures are frequent on the slope above the road, though isolated by thin glacial drift and more still by impressive chutes of debris, which latter increase to a maximum just before Achtriochtan farm is reached. Where the hillside exposures show phyllite they are distinguished by a slabby smoothness. The eye can thus trace the phyllite outcrop, which is clearly bounded north-eastwards by the lava escarpment already mentioned ; while north-westwards it is limited, much more obscurely, by rough rocky slopes, due to Fault-Intrusion just outside the Boundary-Fault. It is almost startling to note how faintly this fault manifests itself in the scenery here, on the north side of the glen, as compared with its diagrammatic showing in An t-Sròn across the way.

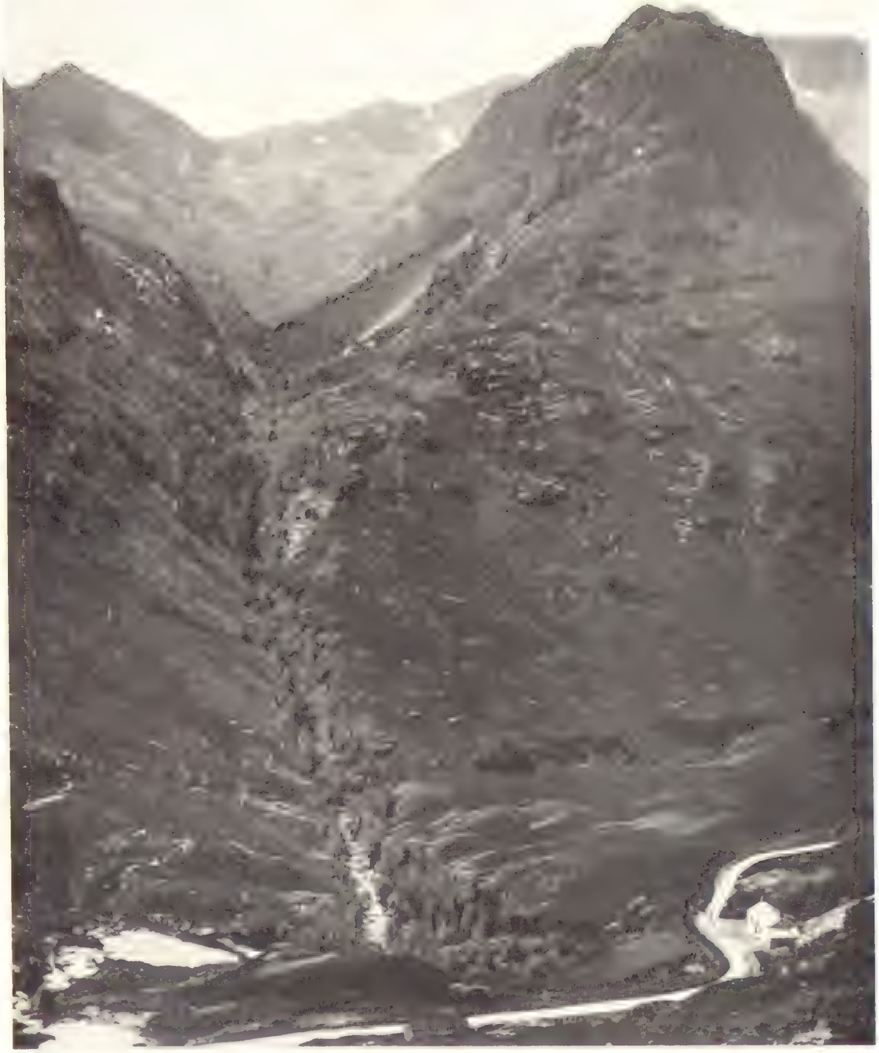
Andesite of Group 1 first appears at the roadside in a knob upon which Achtriochtan farm is built (S 39706). This may well be the lowest flow ; but to hammer the basal sediments described in the following section (p. 142) one has to go one or two hundred yards north of the road.

From Achtriochtan farm onwards for the next mile and a half there are frequent roadside exposures of Group 1 andesites or basalts. They are all very fine-grained, and it is often impossible to discern their crystalline texture with a pocket lens—though they are not flinty like the overlying rhyolites. Amygdaloidal developments are very restrained.

While traversing these lavas the road, between half and three-quarters of a mile east of Achtriochtan farm, crosses two more very impressive chutes of debris. These have been fed by intermittent streams that have etched the face of the Chancellor (an English name replacing Am Bodach, The Old Man). The streams have been guided by shatter-belts and porphyrite dykes. It is clear that some at least of these shatter-belts are of quite early date, for two of them running N.-S. have persuaded porphyrite dykes to forsake temporarily their normal north-east direction.

A quarter of a mile past the more easterly of the major debris chutes descending from the Chancellor, the road bears to the right at a rock cutting. There can be no mistaking the position, for east of the cutting there is a milestone reading 25 miles to Tyndrum and 12¼ to Kinlochleven. The cutting shows basalt in part reddened, possibly by contemporaneous weathering, and traversed by a characteristic north-east porphyrite dyke, 10 feet wide. The exposure has a special interest in that the lava affords specimens of the rare pink manganese epidote called withamite (Brewster 1825 ; Heddle 1898, p. 355). The mineral occurs in small crystals occupying a central position both in amygdales and in the infillings of narrow cracks. Maufe traced this withamite-bearing lava (S 11615) down to the River Coe, and noted a good exposure where the old deserted road runs for 200 yards in a south-easterly direction, aiming directly at the mouth of Allt Coire Gabhail.

A couple of rhyolite flows, both belonging to Group 2, are interbedded among andesites in the Chancellor, and in certain lights they can be recognised from the road. The upper one, or another in like position, reappears in a conspicuous comrade crag, called A' Chailleach (The Old Woman), a mile to the south-east. It is pink or red and can as a rule be easily identified even at a distance.



MEETING OF THREE WATERS, GLEN COE; AND ROCK-FALL, ALLT COIRE GABHAIL

The lower of the two Chancellor rhyolites marks the base of Group 2. It has been traced for a mile and a half along the north face of the glen until, due south of A' Chailleach, it reaches the valley bottom to join with the exposures of the more spectacular mountains across the glen.

The Three Sisters of Glen Coe, Aonach Dubh (Black Ridge), Geàrr Aonach (Short Ridge) and Beinn Fhada (Long Mountain) dominate the view to the south. All three are spurs of Bidean nam Bian (Peak of Hides or Deer Skins). Their main features, outlined in the previous section, can easily be followed in the scenery with the help of the geological one-inch map coupled with Fig. 19. Above all, one recognises the special grandeur of the thick rhyolite flows of Group 2 (Pl. VI, p. 133) and the ease with which their junction with the augite-andesites of Group 1 can be traced, if we disregard very minor instances of interdigitation.

Among other points of interest in the view to the south we note that several porphyrite dykes of the Etive Swarm can be recognised. A good example of such a dyke cutting through the rhyolites of Aonach Dubh has for a stretch fallen away in blocks thus producing in the cliff a conspicuous cleft, the mythical Ossian's Cave, sometimes visited by climbers (Fig. 22). Again at the foot of Geàrr Aonach, west of Allt Coire Gabhail, the rhyolite crags are traversed by half a dozen grassy lanes floored by porphyrite dykes (Pls. VI, VII).

Allt Coire Gabhail (Stream of the Corrie of Capture) is itself guided by a porphyrite dyke, and has for some distance disappeared under a considerable landslip precipitated from Geàrr Aonach (Pl. VII). An alluvial strath has formed behind the landslip, and in the days of clan warfare served as a convenient hiding place for captured cattle.

Allt Coire Gabhail, directed as we have seen by a porphyrite dyke, drains north-eastward ; and, downstream from the landslip, it has cut a deep gorge. The Coe (left bottom corner of Pl. VII) in its general westward course has also met this particular dyke (which crosses the old road just beyond the cottage), and has eroded its course for a short distance south-westwards along it. Thus two about equally matched currents meet head on, and their combined torrent escapes at right angles, west-north-westwards along a transecting gorge that is guided by a monchiquite dyke, of probable Permian date. This monchiquite (lettered C on Sheet 53) has been recognised at intervals for five miles; and at the collision juncture of Allt Coire Gabhail with the Coe it has located a third incoming stream, called Allt Doire-bheith (Stream of the Birchwood), entering from the east-south-east (that is from the left in Pl. VII). Thus Nature, taking advantage of two intersecting dykes, has arranged what has come to be known as the Meeting of Three Waters.

At about this point a great upward step affects the bottom of Glen Coe, a step corresponding with the crossing of the lowest persistent rhyolite of Group 2 that extends on the one side to Aonach Dubh and on the other to the Chancellor. Though for half a mile above the Meeting of Three Waters the Coe still flows over andesites of Group 1, the influence of the resistant cover of rhyolite is already obvious. Broadly speaking the bed of the river, from Loch Leven to a point a quarter of a mile downstream from the Meeting of Three Waters, rises 400 feet in 5½ miles. From here to the fourth of a succession of bridges, which we shall soon be crossing (Fig. 22), it rises four and a half times as quickly, 500 feet in 1½ miles. Upstream from this bridge to the watershed west of Lochan na Fola (Bloody Lochan, named after a brawl) it rises much more gently again, 100 feet in one mile.

At the step, the Coe has incised itself into the bottom of the glen, cutting a gorge along intersecting zones of weakness; and it has already succeeded in eliminating all falls and cataracts along its own course. In doing so, however, it has outstripped its tributary Allt Lairig Eilde that enters upstream beyond Beinn Fhada (Fig. 22). Accordingly this important tributary is left hanging, and discharges as a picturesque waterfall into the post-glacial part of the chasm excavated by the Coe. This affords a favourite spectacle for tourists, and special laybyes have been arranged for buses.

The new road, which we are following (Fig. 22), by means of cuttings and bridges keeps close by the line of the river, so that, starting with an initial advantage of about 100 feet, it is able to maintain an easy uniform gradient, combined with fairly long limbs, between three almost rectangular bends. The manner in which the upstep of Glen Coe has been negotiated, and the precautions taken further back where fans of debris have been crossed, afford fine examples of civil engineering.

Welcome as are the close views of the river mentioned above, they are on the whole less impressive than what can be seen, hereabouts, at a higher level from the old road, now only available to walkers. Anyone with time to spare should make a point of visiting both, and the laybyes at the fall make this easy for motorists. The high-level view is best approached from the east, by leaving the new road for the old between the closely adjacent second and third bridges upstream from the Allt Lairig Eilde fall. Both roads are here on the north side of the Coe, the new road a little lower than the old. Having reached the latter, one proceeds westward for quarter of a mile to the foot of An t-Innean Mòr (Great Anvil or Stiddy, now commonly corrupted to Study). Here a cairn, shown on Fig. 22, by the side of the old road marks a view-point chosen for Queen Victoria's lunch during a visit to the West Highlands. The advantage of approach from the east is that at first the old road, at a little over 800 feet approximates to the general level of the bottom of what may well be called Upper Glen Coe. Then at the Queen's Cairn it brings one suddenly into view of Lower Glen Coe, 300 feet below. It is argued in chapter i that Upper Glen Coe still owes much of its character to an initial eastward-draining river, while Lower Glen Coe has been profoundly transformed by reversed drainage making for the west.

Though approach to the Queen's Cairn from the east is recommended because of its specially dramatic quality, approach from the west is very easy, again on foot. The old road cannot be missed where it climbs up above the new road along a ramp ¼-mile N.E. of the Meeting of Three Waters. In a quarter of a mile it rises 130 feet to the Queen's Cairn.

Other items in the view from this cairn are tracks of north-east porphyrite dykes crossing the lower slopes of Beinn Fhada and Buachaille Etive Beag, exactly comparable with those already noted at the foot of Geàrr Aonach.

Still another reason for visiting this locality is afforded by the intensely corrugated fluxion-banding of the rhyolite on which the Queen's Cairn stands. This is the basal rhyolite of Group 2, in large measure responsible for the preservation of Upper Glen Coe.

Let us now return to the new road by descending the ramp ¼-mile N.E. of the Meeting of Three Waters. At the bottom, let us turn eastwards towards the Allt Lairig Eilde fall. For 300 yards there are good roadside exposures of an andesite lava that serves as top to Group 1, until it passes in clear section under the Queen's Cairn rhyolite of Group 2. A first glance at the road cutting may give the false impression that the rhyolite is filling pockets on an uneven surface of the andesite, here somewhat amygdaloidal ; but the illusion is due to the dark-grey andesite having been bleached white in patches where until recently it has been overlain by peaty soil. Close examination shows that the plane between andesite and rhyolite dips evenly and gently, reaching the road surface opposite the most westerly of the laybyes arranged for views of the river gorge. Here the exact line of demarcation is emphasised by a two-inch bed of fine-grained black volcanic sandstone, fairly rich in minute detrital flakes of muscovite in addition to plentiful volcanic debris. Slices (S 39698-9) show this interesting sediment to be slightly disturbed by the overlying rhyolite,here a crypto-crystalline devitrifying glass.

For the next 150 yards the road cutting exposes the rhyolite as a breccia, presumably a basal flow-breccia rather than an independent ash. Slices (S 39697, 39700) from near the base have patches rich in epidote ; while (S 39701) from near the top is a much cracked mosaic of felspar and quartz. There has probably been a lot of stewing immediately after eruption. Then follows in the road cutting and in the river gorge a magnificent show of gently and evenly inclined flow-banding, contrasting strongly with the corrugated display higher up in the same flow at the Queen's Cairn. About a dozen north-east dykes, porphyrite and lamprophyre, are seen in the half mile of cutting that traverses the rhyolite outcrop.

Exposures of the Queen's Cairn rhyolite continue past three bridges that carry the road to and fro across the Coe and end near an imposing cairn, between river and road, which stands at the start of a path that leads through Lairig Eilde (Pass of the Hind) to Dalness. Here the rhyolite is followed by overlying andesite which extends along the road for the next quarter of a mile until the fourth and final bridge of the series is reached. This andesite belongs to one of the numerous andesite intercalations characteristic of the Beinn Fhada development of Group 2 (p. 135) ; and it connects these with the andesite flows that separate the Queen's Cairn rhyolite from that of A' Chailleach to the north.

We have now come approximately to the flat axial region of a syncline determined by the tendency of the lavas to dip away from the curved course of the Boundary-Fault of the Cauldron-Subsidence. So far along the road, all the way from Achtriochtan, the prevalent dip of the volcanics has been south-easterly. Before long, however, we are to enter a belt with pronounced south-westerly dip, which, combined with drastic overlap, brings Moine Schists (Eilde Flags) to view at Cnoc nam Bocan (Goat Hillock). Deficient exposures, a certain confusion of dips, and irregularities in the succession make it doubtful where exactly the centre of the syncline lies. Maufe, who mapped the ground, thought that the andesite we have just mentioned is the highest volcanic rock preserved anywhere in the bottom of Glen Coe. The writer, after re-examining the evidence since the making of the new road, is of a slightly different opinion. He thinks, without being quite certain, that, immediately east of the fourth bridge, this andesite passes under agglomerate followed in turn by porphyritic rhyolite, and that the latter, which outcrops conspicuously along the road for the next three-quarters of a mile, is really the highest rock encountered in our traverse. It is remarkable, therefore, that, where last seen at the roadside, this porphyritic rhyolite comes within a quarter of a mile of the Moine Schists (Eilde Flags) exposed at Cnoc nam Bocan—a consequence of overlap.

Agglomerate, with one short interruption by andesite, is the first rock seen north of this porphyritic rhyolite in its west to east course along the road. It would seem to be the same agglomerate as that noted above east of the fourth bridge ; and its continuation south-eastwards from Lochan na Fola has been mapped across the River Coupall to Stob Dearg (Red Peak).

Exposures are fairly good along and beyond the old road which lies a little to the north of the new road, and they show conclusively that the Lochan na Fola agglomerate crosses it with a steep south-westerly dip. The following succession emerges from beneath the agglomerate within a distance of about 500 yards measured along the new road : rhyolite, andesite, rhyolite. The last-named has been excavated in a large shallow quarry on the south side of the road, an ideal place to park or turn a bus. Just beyond is a notice-board, reading : Cnoc nam Bocan Summit 1,024 ft.

The quarried rhyolite may quite possibly be the same as the Queen's Cairn flow at the base of Group 2 in the standard sequence of the west. At any rate it occupies approximately the same position in the volcanic pile ; yet here it rests on Moine Schists that make the actual hillock of Cnoc nam Bocan immediately to the north. The juxtaposition is not due to faulting. Maufe found thin basal conglomerate intervening on the old road, and, though this particular evidence has since been covered, basal sediments can easily be followed for about a mile where the unconformable contact continues north-west obliquely up the valley side.

The overlap recognised at Cnoc nam Bocan is characteristic of all the north-eastern margin of the Glen Coe volcanics. It is, for instance, diagrammatically seen at the base of the magnificent Stob Dearg, which stands full in view a mile to the south-east (p. 146).

Looking in the opposite direction one can grasp that Cnoc nam Bocan lies well within the Cauldron-Subsidence. The Boundary-Fault passes at the foot of Stob Mhic Mhartuin (p. 160) a mile to the north-west, and then continues without special features, to cross the road three-quarters of a mile beyond Altnafeadh.

One last point. While the summit post at Cnoc nam Bocan marks the summit of the road, the flat inconspicuous watershed of the valley itself lies half a mile further east, the other side of Lochan na Fola, at almost exactly 1000 feet. Looking east past Altnafeadh along the Moor of Rannoch (R. in Fig. 1 ; also Fig. 18) we can easily restore in imagination the supposed eastward-draining river that has now had its waters redistributed to the westward-flowing Coe and the south-westward-flowing Etive.

C. NORTH SIDE OF GLEN COE : ESPECIALLY BASAL SEDIMENTS

Introduction.—The road traverse just described, supplemented by Sheet 53 or Fig. 19, allows us to realise the main features of the volcanic succession displayed north of the Coe, except that it does not cross exposures of basal sediments. These sediments are quite thin and are probably of different dates in different exposures owing to the marked overlap from west to east. To clarify matters, the present section, though devoted primarily to the basal sediments, starts with a concise summary of their volcanic associates which alone reveal the rather confusing overlap. Some repetition from Section B is unavoidable, but additional facts are introduced.

Volcanic Rocks.—Owing to sharp upward tilt of the volcanic series in the neighbourhood of the Boundary-Fault (Fig. 21), only Groups 1 and 2 of the standard sequence are found on the northern flanks of Glen Coe. Moreover, the distinction between the two groups is not always clear, for Group 2, instead of being all rhyolite, as in Aonach Dubh (Fig. 20), is a mixed assemblage of rhyolite and andesite, as in Beinn Fhada (p. 135), and its andesites sometimes directly overlie others belonging to Group 1.

A rhyolite lava in the basal portion of Group 2 is traceable for a mile and a half from the Queen's Cairn to the lower slopes of the Chancellor (Figs. 19, 22). All the andesites outcropping between it and Achtriochtan farm obviously belong to Group 1 ; but in Aonach Eagach these same andesites are overlain by others which further east, in the Chancellor, lie above the Queen's Cairn rhyolite and therefore belong to Group 2.

On top of the Chancellor andesites, that is some way up in Group 2, a second rhyolite appears. Westward it caps the Aonach Eagach andesites at Meall Dearg. East-south-eastwards it, or another in approximately the same position, is responsible for the crag A' Chailleach where it is interbedded among andesites.

The upturned base of the volcanic series is seen north of A' Chailleach in Coire Mhorair and Coire Odhar-mhòr (Figs. 21, 23-5, pp. 134, 156, 158, 159). The lavas are all andesites without any sign of the Queen's Cairn or A' Chailleach rhyolites ; but hornblende-andesites appear near the bottom and are more likely to belong to Group 2 than to Group 1.

Where the base of the volcanic series reappears to run obliquely down the hillside from west of Stob Mhic Mhartuin towards Cnoc nam Bocan (Fig. 22) it consists for three-quarters of a mile of agglomerate with locally an underlying andesite. Half a mile before reaching the road this agglomerate seems to unite with another on a slightly higher horizon. The combined agglomerate, crossing the road at Lochan na Fola, then runs south-eastwards well up among the rhyolites of Stob Dearg.

At the road the downward succession from the Lochan na Fola agglomerate to the emergence of Moine Schists (Eilde Flags) at Cnoc nam Bocan is : rhyolite, andesite, rhyolite. As may be gathered from the account already given of the road traverse, this last rhyolite resting on the Moine Schists is, at any rate approximately, on the horizon of the Queen's Cairn flow at the base of Group 2.

It is thus clear that basal sediments near Achtriochtan farm are likely to date from an early stage of Group 1, whereas basal sediments near Cnoc nam Bocan are more likely to represent the latest stage of this group. At the same time it is possible that basal sediments anywhere may be considerably older than immediately overlying lavas or ashes. H. B. M., E. B. B.

Basal Sediments.—Thin basal sediments are seen at a number of places at the foot of the precipitous crags that mark the oncoming of andesites of Group 1 on the slope north-west of Achtriochtan farm. One of the most interesting lies between the 1000-ft and 1250-ft levels half a mile from the farm. The following succession dips at 30° to the south-east :

	ft
Andesites	—
Fine grit	2½–3
Green shales	1–3
Coarse conglomerate	about 30
Green micaceous shales with plant remains	not more than 20

These sediments are of a local character and are not traceable far in either direction. A short distance further up the hill towards the left the section in the basement beds is :

	ft
Compact banded green shale passing down into green sandstone	12
Coarse pebbly grit	10
Red and green shales with sandstone bands	8
Fine grit	5
Conglomerate	20
Silvery greenish phyllites	—

A thin felsite sill is here intrusive along the plane of unconformity between the conglomerate and phyllites (Leven Schists). The conglomerates consist of well-rounded boulders and pebbles of quartzite, phyllite, andesite, and "granite," and an occasional pebble of quartz-porphyry, in a gritty matrix, which is often very felspathic. The shales are mostly purple and sandy, but occasionally contain bands of darker and more argillaceous material.

Sections from the "granitic" boulders were examined and found to be quartz-diorites rather than granites. One section shows (S 10285) much idiomorphic plagioclase, altered biotite, calcareous patches after another ferromagnesian mineral, and some interstitial quartz. In some there is altered green hornblende, and augite may also have been originally present (S 10286, 10287). Another section is from a biotite-granite (S 10288). These rocks are of types common among the unfoliated "granites" of the Highlands, and would appear to have been derived from one or more closely associated plutonic masses. The boulders are often large and always well rounded. They do not resemble any of the varieties of "granitic" rocks (Fault-Intrusion) found in the immediate neighbourhood, nor could they possibly have come from any portion of the Ben Cruachan—Ben Starav Pluton, since this, as will be shown in the sequel, is of later date than the volcanic rocks overlying the conglomerates. The most abundant boulders are those consisting of white quartzite ; they reach a length of 3 ft. The larger ones are well rounded, the smaller more sub-angular, and many of them have their surfaces stained red. Two boulders of a basic plutonic rock much decomposed but resembling the kentallenite of Aonach Dubh a' Ghlinne were noticed. Boulders of pyroxene-andesite are fairly plentiful, and a few pebbles of hornblende-andesite were found, but none of rhyolite or porphyrite. The matrix of the conglomerate is generally a coarse grit, but in some places a sandy shale. Altogether the conglomerate resembles the boulder-gravel in the bed of a torrential stream.

H. K., H. B. M.

A small patch of basement conglomerate is seen again with like characters in Coire Càm at the foot of Meall Dearg, where it is overturned at an angle of 70° in close proximity to the Boundary-Fault (Fig. 23, p. 156). There is a further exposure of the base of the group in the stream-bed of Coire nan Lab, but the conglomerate is absent here and the sedimentary beds consist mostly of shale. The base is also seen in Coire Mhorair and Coire Odhar-mhòr situated further to the east (Figs. 24, 25, pp. 158, 159, and Section III, Fig. 21, p. 134). In the immediate vicinity of the Boundary-Fault the beds are locally overturned ; elsewhere they dip steeply away from the Boundary-Fault towards Glen Coe. From the southern flank of Sròn a' Choire Odhair-bhig a band of ashy grits, shale and conglomerates, resting unconformably on the schists and succeeded by coarse agglomerate and lavas, may be followed fairly continuously down to the Glen Coe road half a mile west of Altnafeadh. Along this line the dip, in conformity with the change of trend of the Boundary-Fault, is directed towards the south-west at various angles.

E. B. B.

D. SEQUENCE ON BUACHAILLE ETIVE MÒR

The volcanic series in ascending order consists of : (1) basement breccia, with intercalated flows of andesite ; (2 and 3) rhyolites and rhyolitic flow-breccias, with intercalated and overlying agglomerate and sediment ; and (4) hornblende-andesites. These together attain a thickness of at least 2500 ft (Sections I, II, Fig. 21, p. 134).

Group 1.—The breccias at the base of the series are usually coarse and made up largely of angular fragments of quartzite and quartzose schists. These may have been derived quite locally, and rarely attain 6 in. in diameter. Here and there throughout the breccias thin beds of finer material are met with, and as they are well bedded it appears they must have been laid down under water. The general characters of these deposits are well seen beneath rhyolite lavas on the north face of Stob Dearg, where they form smooth rock-slopes towards the base. The best section occurs beneath a conspicuous overhanging slab which can be easily recognised in the photograph (Pl. VIII, p. 146) at the lower limit of the rocky portion of the hill. The sequence, where the beds are thickest, is as follows, in descending order :

	ft
Bedded breccia often resembling conglomerate, with fragments of quartzite, micaceous schist, and some of felsite in a gritty matrix	—
Red shales with cornstones	14
Purple shales	4
Greenish and black shales, showing alternations of coarser and more sandy layers with finer bands	10
Conglomerate, with angular and subangular boulders of quartzite and quartzose schists (Eilde Flags) in a green sandy matrix	20
Green shales, some red, and irregular bands of conglomerate	18
Fine greenish basement breccia containing quartzite fragments	1–2
Quartzite, much shattered at the surface	—

A band of dark shales at the base of the same overhanging crag a little farther to the north yielded Tait and Peach several remains of plants. Among these are stems of which R. Kidston and W. H. Lang have written as follows: " They are not *Psilophyton* but narrow, linear, dichotomously-branched axes without hairs or spines ; many of the branches end in what appear to be hemispherical sporangiumlike bodies " (1924, p. 608). Along with these are numerous, exceptionally well preserved *Pachytheca*, which these authors place in a new species *P. fasciculata*. They point out that the genus *Pachytheca* is probably algal, and that it is abundantly represented in the Lower Old Red Sandstone of Scotland, England and Wales, but is also found in the Downtonian and Wenlock of England. The Wenlock species is certainly not *fasciculata*, while the Downtonian specimens and most of those from the Lower Old Red Sandstone are too poorly preserved to allow of close comparison. The genus is not known from either the Middle or Upper Old Red Sandstone of Scotland (1924, pp. 610-612).

At the north-eastern end of Buachaille Etive Mòr, lava-flows of andesite intercalated with the basement breccia, and with them representing Group 1, are so thin that they cannot be shown on Sheet 53. They are seen on the banks of the stream flowing down past Lagangarbh cottage south of Altnafeadh, and again near the river Etive on the south-east slopes of Stob Dearg. They appear to represent the north-eastward thinning of the andesites so well developed in Aonach Dubh and about Dalness. The rocks are sometimes vesicular, show specks of pyrites but no conspicuous phenocrysts, and may be dark grey or light grey. Under the microscope (S 12490, 12772) they are seen to be very much decomposed : pseudomorphs after some ferromagnesian mineral are set in a groundmass of cloudy felspar laths, with interstitial epidote and iron-ores. Vesicles are frequent, and are filled with calcite and pyrites.

In the area about Dalness, that is at the south-west end of Buachaille Etive Mòr, a greater development of andesite lavas is accompanied by breccias which in the main consist almost entirely of fragments. These andesitic breccias could not be separated from the lavas in mapping ; but, intercalated near the top of the series, is a mappable bed of quartzite breccia, which runs round the south-west spur of Buachaille Etive Mòr and dips gently to the north-east.

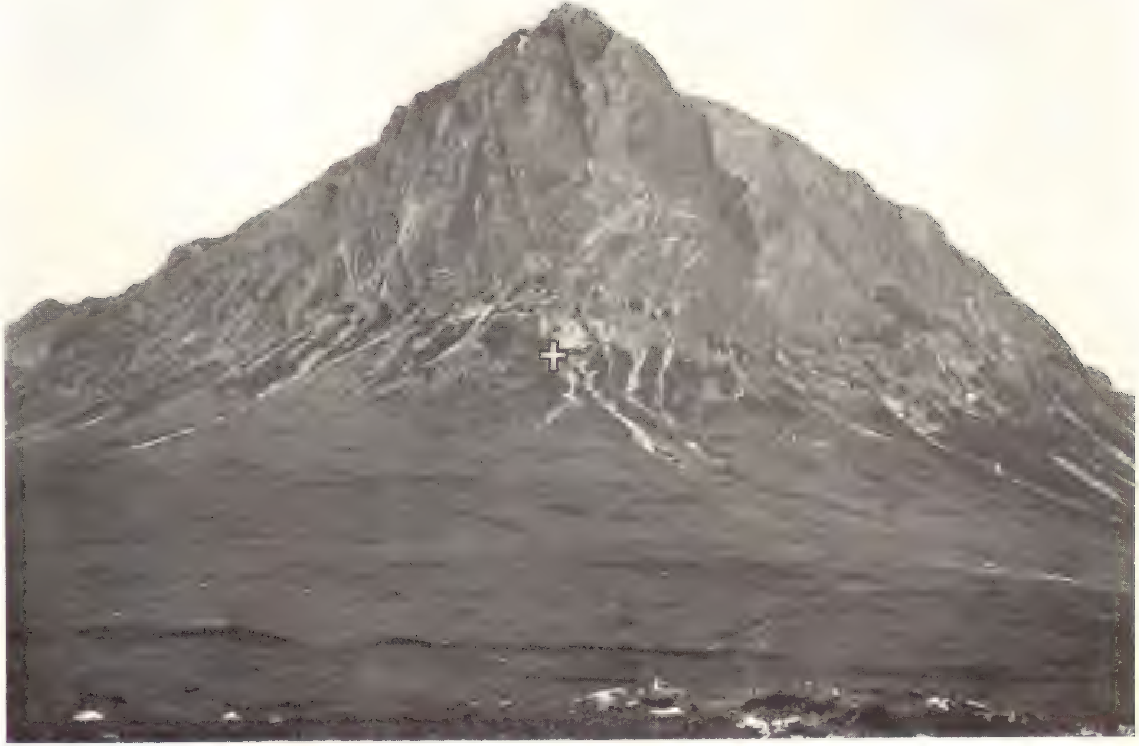
Group 2.—Resting on the basal sediments and andesites are the rhyolites and rhyolitic flow-breccias of Group 2, which attain a thickness of about 1500 ft on the north face of Stob Dearg (Pl. VIII). The precipitous character of this peak is entirely due to these rocks. The rhyolites tower up in huge vertical walls and precipices, while numerous joint planes often form a series of step-like ledges, and sometimes give the rock a rudely columnar appearance. The scenery formed by these flinty-textured masses cannot fail to impress anyone who has seen the imposing and precipitous eastern face of Stob Dearg, the highest point (3345 ft) of Buachaille Etive Mòr. Here the lower rhyolites are free from fragments, but throughout the rest of this area they are of the nature of flow-breccias containing abundant fragments of other rhyolites, hornblende-andesites, and, frequently, of schists as well. On Stob na Bròige, the south-westerly summit of Buachaille Etive Mòr overlooking Alltchaorunn cottage, these flow-breccias, although their basal portion has been cut off by the Cruachan " Granite," attain a thickness of over 1500 feet without reaching their upper limit.

Marked metamorphism has been induced by the Cruachan " Granite " throughout much of the district. The altered rhyolites assume a red colour with partial obliteration of their characteristic flow structure.

It is considered probable that a red felsitic rock which forms the top of Stob Dearg may really be intrusive although it is grouped with the rhyolitic lavas in the published map. It has a well-defined fluxion edge without any accompaniment of fragmental material.

Intercalated with the rhyolites are beds of agglomerate, flows of andesite, and an occasional parting of shale. The most important bed of agglomerate is mapped as continuous with the band exposed at Lochan na Fola on the Glen Coe road, and forms a large part of the floor of the corrie west of Stob Dearg. Local beds of red sandstone and shale occur along with it, and one of them, situated near its base, is well seen on the ridge forming the western margin of the corrie. To the east the agglomerate thins out until represented by only a few feet of dark purplish and greenish shales. These run diagonally down the eastern face of Stob Dearg and have given rise to the feature known to mountaineers as the " Crowberry Traverse." The shales here are less steeply inclined than in the corrie west of Stob Dearg, on the west side of which they are sometimes vertical. A thin parting of shaly beds, though much shattered by lines of fault and crush, is well seen in a gully immediately to the south-east of the " Crowberry Traverse," and is accompanied by a bed of ash about 2 ft thick. Other bands of ash occur among the lavas south of the peak, and are seen in thin slices under the microscope to consist chiefly of comminuted glass fragments, with typical ash-structure, and accompanied by a few recognisable pieces of rhyolite and hornblende- and pyroxene-andesites. Slices of the agglomerate show fragments of igneous and metamorphic rocks in varying proportions, set in a matrix of quartz grains and comminuted igneous rocks (S 12477, 12487). In cases where there is only a small proportion of schist, and the agglomerate consists almost entirely of igneous matter, the distinction between it and rhyolitic flow-breccia becomes very difficult, and, in fact, impossible once the rocks have been even slightly altered (S 12470, 12487, 12784).

The andesite intercalations, met with occasionally throughout the group, are most numerous near its base in the Dalness area. Where the junctions are well



STOB DEARG
Rhyolite lavas (crags) on schists (grass covered). Fossils at +

seen, it sometimes appears as though the andesite was of the nature of an inclusion in the rhyolite, since there is no vesicular margin between the two, while the general outline of the junction does not always agree with the strike of the surrounding beds. The andesite which occurs along the " granite " margin, south of Stob Dearg, is regarded as one of these intercalations among the rhyolites of Group 2. The slices prepared from these intercalations show the results of contact-alteration by the neighbouring " granite ". They were originally hornblende-andesite flow-breccias, but the hornblende phenocrysts are now only represented by magnetite skeletons and matted aggregates of biotite or, more rarely, of green hornblende in ragged prisms. Phenocrysts of felspar do not occur. The groundmass consisted originally largely of felspar and granules of some ferromagnesian mineral, but is now a mosaic of felspar, some quartz, and scales of biotite or prisms of green hornblende (S 12511, 12762, 12764).

Group 3.—A bedded breccia full of fragments of the schists represents Group 3 of Fig. 20. It is exposed on the summit ridge of Buachaille Etive Mòr, where it thins out in a southerly direction, just as in Buachaille Etive Beag and Stob Coire nan Lochan.

Group 4.—A small outlier of hornblende-andesites of Group 4 forms the mid peak of Buachaille Etive Mòr, rising to a height of 3325 ft. It includes thin intercalations of rhyolite, but the predominating rock is a dark hornblende-andesite, containing needles of hornblende visible to the eye. Under the microscope the effects of contact-alteration are very marked. The original rock is seen to have contained phenocrysts of hornblende, plagioclase, and sometimes mica.

H. K., G. W. G.

E. SEQUENCE IN CÀM GHLEANN AND SRON NA CREISE

In this, the most easterly part of the volcanic district (Fig. 29), the sequence is similar in many respects to that described on the northern end of Buachaille Etive Mòr. In ascending Càm Ghleann from the position of the Boundary-Fault we encounter several detached outcrops of rhyolite and andesite, and also patches of breccia consisting of angular fragments of schist and rhyolite.

Group 1.—A short distance farther up the glen we come to a coarse conglomerate underlying the main mass of the volcanic rocks. As exposed in the stream it contains, in addition to schist fragments, large masses of various igneous rocks, conspicuous among which are boulders of a red " granite," which attain a diameter of 2 or 3 ft. This " granite " is particularly interesting as it shows some of the characters which distinguish the Moor of Rannoch rock from those later " granites " which are intrusive in the volcanic series. In the hand specimen the quartz is seen to occur in large blebs, and a foliation can sometimes be made out. Under the microscope (S 12788) the quartz appears in composite areas such as are characteristic of the Moor of Rannoch rock ; while the plagioclase is near oligoclase. The fact that in slices these boulders show biotite as their only ferromagnesian mineral (S 12788, 12789) indicates that if they have been derived from the Moor of Rannoch mass, they must have come from its marginal portions as its interior contains hornblende in addition.

G. W. G.

Overlying the conglomerate comes a dark basic andesite which is all that remains to represent the thick basic andesites (Group 1) of the Coire nam Beith section (Fig. 20).

Group 2.—The andesite is succeeded by several feet of shale overlain in turn by thick rhyolitic lavas belonging to Group 2. Except in the floor of the glen, where the andesite is present, the rhyolites form the local base of the series. Their junction against schists is well seen on the northern slopes of Sròn na Crèise, where a thin layer of breccia usually intervenes—Sròn na Crèise, see Sheet 53, is the northern summit of the ridge marked Stob Glas Choire in Fig. 29. On Sròn na Crèise, as on Buachaille Etive Mòr, the volcanic series dips at high angles to the south-east, but in Càm Ghleann and further east it is lying approximately flat and abuts against a steeply sloping surface of schist.

Group 3.—Agglomerates and breccias of Group 3 cap the rhyolites in the large corrie at the head of Càm Ghleann, whence they sweep round to the north-west and cross the Sròn na Crèise ridge until they meet intrusive Cruachan " Granite " (Section I, Fig. 21, p. 134). Eastwards they extend round the head of Càm Ghleann into Meall a' Bhùiridh (Sheet 54, Geol.), to come into direct unfaulted contact with the schists, thus emphasising the remarkable overlap. This also is the condition of affairs in Coire an Easain, where extremely clear exposures illustrate the uneven nature of the floor upon which the breccia accumulated.

The breccias often consist almost entirely of fragments of rocks derived from the quartzose and micaceous schist of the neighbourhood ; but it is impossible to draw any hard and fast line between this breccia and the coarse agglomerate with which it is associated, consisting mainly of fragments of rhyolite and andesite. In some places the breccia is comparatively fine-grained, and full of small angular fragments of quartzose schist and rhyolite, averaging half an inch or less in diameter ; but more usually the main mass of the rock is a confused agglomeratic mixture of angular fragments of all sizes, consisting of quartzose and micaceous schist, rhyolite and occasional blocks of andesite. The fragments of quartzose schist are sometimes two yards or more in length. As the andesites of Group 4 are approached the agglomerate becomes more and more andesitic, and sometimes consists mainly of andesite fragments. The finer-grained portions of the breccia are well bedded, and good indications of bedding are seen on both the east and west slopes of the head of Càm Ghleann. These finer-grained portions are very rich in quartz grains, and sometimes appear to pass into zones of grit. In two or three places on the west side of Càm Ghleann angular fragments of a rather acid biotite-" granite " were observed in the breccias. These fragments are not unlike the " granite " which is exposed further west in Glen Etive, but they cannot possibly have been derived from any portion of the Cruachan or Starav " Granites " since the Cruachan " Granite," the earlier of the two, is in the immediate neighbourhood clearly intruded into the breccias. They must have been derived either from some older mass bared by erosion, or from some quasi-contemporaneous intrusion, fragments of which have been ejected during explosions. The occurrence of " granite " blocks in the conglomerates and breccias of this part of the district may be paralleled with that of Tertiary granophyre and gabbro in the agglomerates of the Cuillin Hills of Skye (*cf.* Harker 1901b, p. 507).

Group 4.—The hornblende-andesites of Group 4 in their normal types succeed the agglomerates, and are remarkably well exposed along the sharp east and west ridge of Meall a' Bhùiridh, and again along the north and south ridge between Sròn na Crèise and Clach Leathad. The rocks weather with a pale greyish or whitish crust, but on fracture they are dark grey or almost black ; and small plagioclase phenocrysts and prisms of hornblende may usually be detected with the naked eye. Flow-structure is also well seen, especially on the Meall a' Bhùiridh ridge. The Cruachan " Granite " has invaded these andesites and sends many veins into them. The junctions with the " granite " in the field are clear and well defined, and decided contact-alteration has been produced. This will be described in chapter xviii.

On the north and east sides of the highest point on the ridge north of Clach Leathad, 20 to 30 ft of dark grey laminated shales and grits occur intercalated in the lower portion of the hornblende-andesite series. These beds are considerably indurated by the " granite," and no signs of fossils were observed in them.

H. K.

F. Sequence around Dalness, Glen Etive

Irregular Floor.—The schistose floor on which the rocks of Old Red Sandstone age rest is seen in several places, both near the River Etive and some distance above it, and is evidently very uneven. On the north bank of the Etive a breccia about 2 ft thick, inclining steeply south-west, separates the andesites from the schists, which here are less siliceous than usual in the adjoining localities. Further up on the south side of the river various inliers of quartzite are exposed at different levels within the andesitic rocks. The surface of the quartzite is generally a good deal broken and frequently partially covered with a skin of breccia.

C. T. C.

In a bed of breccia cropping out round the S.W. end of Buachaille Etive Mòr large masses of quartzite appear, and are well seen in Allt Gartain, half a mile up from Dalness, and also on the slope about half a mile E.N.E. of the house. The smaller of these masses, associated with a bed composed of quartzite fragments, appear at first sight to be merely particularly large boulders ; but one very large mass in Allt Gartain is evidently in place. It is probable then that they are all stacks surrounded by the volcanic rocks, and that the breccia-bed is scree-material showered down upon and finally covered by the advancing lavas.

Group 1.—The basic andesites of Group 1 may be traced continuously from the type section of Coire nam Beith (Fig. 20) along the south-western flanks of Bidean nam Bian to the neighbourhood of Dalness. Though not so thick as in the type section, they present a greater development here than in the district to the north-east. As already mentioned in describing Buachaille Etive Mòr, these andesite lavas are accompanied by andesitic breccias, so similar in appearance as to be inseparable for mapping purposes. G. W. G.

The andesites exposed in the river Etive between 200 yards and three-quarters of a mile east of Dalness have suffered considerable contact-alteration. Weathered surfaces are usually very knobby, with prominences greener and more epidotic than the rest. Perhaps these represent the parts which were the most decomposed at the time of the intrusion of the neighbouring " granite." Exposures sometimes show conspicuous oval forms rather like the pillows of pillow-lavas, the outer rims of which for the breadth of half an inch or so project a little, but the vesicles show no arrangement parallel to these rims.

Many parts of the rock have a brecciated aspect, the angular pieces frequently fitting into one another very exactly, with hardly any matrix between. In numerous cases cracks penetrate pieces of andesite for a certain distance and then come to an end as if they had been developed during violent rolling or on falling. It is not clear that any true ash is present.

The amygdales often project considerably on the weathered face. They are usually much elongated and consist of epidote, or epidote and a pale green hornblende. Other vesicles are filled with quartz, apparently in a granular or granulitic condition, and to a less extent with plagioclase (S 11488).

In one locality a number of thin veins which cross the local trend of the vesicles almost at right angles were also seen to contain a pale hornblende in considerable abundance.

The development of hornblende and felspar in the vesicles, and of hornblende in the veins, is doubtless due to contact-metamorphism, probably exerted by the neighbouring " granite," and it may be concluded that the lavas were considerably decomposed and crossed by strings of carbonate before the metamorphism was effected (*cf.* Harker and Marr 1891, p.297).

On the hillside three-quarters of a mile W.S.W. of Dalness an important band of clastic material, sometimes perhaps 300 ft thick, intervenes between the andesites and the overlying rhyolitic rocks of Group 2. The character of the clastic beds varies rapidly from place to place. In the burn rather more than three-quarters of a mile E.S.E. of Dalness the group is almost entirely composed of coarse breccias of quartzite and andesite, and it is noticeable that the pieces of andesite are often more porphyritic than the underlying andesite lavas. At the very top of these beds there is a little fine-grained highly-altered sandstone containing pieces of quartzite. In the adjacent crags the following succession in descending order can be made out, but the middle group appears to die out rapidly in a westerly direction :

	Thickness ft
Breccias composed of quartzite and andesite, with occasional bands of sandstone, sometimes ashy	50
Grey and pink sandstone with fragments of quartzite	60
Breccia composed of angular pieces of quartzite from 5 in. to 12 in. in length : very little fine matrix	50

The above beds are in some places almost horizontal, but in others inclined at gentle angles to the S. or S.S.W. They are often greatly altered, being close to the " granite ".

Group 2.—The highest members of the volcanic series preserved on the slopes of Beinn Ceitlein are composed of 1000 ft or so of rhyolitic rocks belonging to Group 2. In certain weathered exposures many of them show included fragments ; but no vesicles or distinct flow-structures are seen. Ashes as well as lavas may be present, but a separation has not been attempted owing to the masking of original differences by contact-alteration. C. T. C.

G. FISSURE-FILLINGS OR OUTLIERS

Reference may now be made to certain breccia patches, found in the vicinity of the Glen Coe Boundary-Faults, which have given rise to differences of interpretation. Clough and Maufe regarded the examples which occurred in their ground as outliers preserved in hollows of a very irregular erosion surface ;

whereas the writer thinks that the majority, if not all, have formed in volcanic fissures, extending in some cases far below the land surface of the day, and filled in part from above, in part from the depths. Here are examples.

(1) In the corrie at the head of Gleann Chàrnan (nat. grid 122517) Kynaston mapped a small mass of appinite piercing a breccia shown as c_1 on Sheet 53. This breccia is made up of large subangular blocks of the adjoining Leven Schist mixed with a few fragments of quartzite. The writer considers that it choked an explosion vent up which appinite subsequently rose. He recalls how in the island of Colonsay (Sheet 35, Geol.) a suite of basic intrusions, very similar to the Gleann Chàrnan appinite, is associated in like manner with breccias which seem to include material that has tumbled down explosion pipes (Wright and Bailey 1911, p. 34) ; and he extends just such an interpretation to a patch of breccia intruded by related augite-diorite in Lismore (Sheet 45, Geol.). On the other hand Maufe (*in* Kynaston, Hill and others 1908, p. 80) has interpreted both the Gleann Chàrnan and the Lismore breccias as superficial deposits still *in situ.*

(2) A larger breccia patch, also shown as c_1 on Sheet 53, has been mapped at a height of 2500 to 3000 feet on Sgòr nam Fiannaidh, north of Glen Coe (nat. grid 137581). Maufe describes it as resting against a steep slope of quartzite, and as consisting of quartzite fragments, together with small pieces of red felsite and porphyritic andesite, set in a siliceous matrix. It is pierced by Glen Coe Fault-Intrusion.

(3) Four miles further east, a small patch of breccia occurs surrounded by quartzite between two branches of the Glen Coe Boundary-Fault near the foot of Sròn a' Choire Odhar-bhig (Fig. 24, p. 158 ; see also Fig. 26, p. 160).

(4) From half to three-quarters of a mile in front of the highly tilted lavas of Stob Dearg there is a belt extending from the Devil's Staircase to Glen Etive and Càm Ghleann, along which exposures of rhyolite and breccia are constantly making an appearance. The belt for the most part passes through ground much obscured by glacial deposits, and often its existence can only be recognised in isolated stream sections. Careful examination of that part which passes south-west of Stob Beinn a' Chrùlaiste, above Altnafeadh (Fig. 28, p. 163), shows various irregular outcrops of rhyolite, often separated from the adjacent schists by thin breccias, and therefore allied in their behaviour to the lavas of the district rather than the intrusions. The breccias here consist of small angular fragments of schist. In the Coupall River, along this line, pieces of rhyolite are also common.

(5) Clough found small patches of sandy breccia in contact with quartzite at several places across the River Etive from Dalness. One set at the north end of Beinn Ceitlein, a mile south-east of Dalness, is closely associated with rhyolitic bands, some of which are clearly intrusive. Another set, midway to Dalness, is free of rhyolite. Both lie south-west, that is outside, of the main branch of the Boundary-Fault, which introduces the continuous volcanic outcrop of Dalness and Glen Coe ; but they are included within an outer, comparatively gently inclined branch exposed on the western slopes of Beinn Ceitlein. E. B. B.

H. Summary of Volcanic History

(1) The Glen Coe volcanic rocks are in all probability of Lower Old Red Sandstone age.

(2) They accumulated on an uneven floor carved by erosion in the Highland Schists, and show strong overlap from south-west to north-east.

(3) In a few cases patches of breccia and rhyolite seem to mark the sites of volcanic fissures.

(4) The lavas are basic andesites (including basalts), hornblende-andesites, and rhyolites. Their extremely irregular arrangement *inter se* indicates that they were supplied from neighbouring independent vents. The basic flows frequently show reddened tops as if affected by contemporaneous weathering.

(5) The agglomerates of the period cannot be distinguished with certainty from scree-breccias.

(6) The sediments accompanying the volcanic rocks are of quite restricted occurrence. They include screes and torrential conglomerates, along with shales and grits which appear to have gathered in temporary lakes. Plant remains including *Pachytheca fasciculata* have been found in shale at the foot of Stob Dearg. Shale sometimes fills the crevices of the lavas of the bottom group consisting of basic andesites.

(7) Away from the faulted margin of the area the volcanic rocks dip at varying angles towards the south. H. B. M.

CHAPTER XII

ROCKS OF LOWER OLD RED SANDSTONE AGE

BOUNDARY-FAULT AND FAULT-INTRUSION OF GLEN COE

THE volcanic series of Glen Coe occupies a cauldron-subsidence, circumscribed by a fault of some thousands of feet downthrow (Figs. 18, 19). The cauldron, which measures 9 miles by 5, dates, in all probability, from the Lower Old Red Sandstone period, and does not, we need scarcely add, find expression as a hollow in the topography of to-day. At its initiation the boundary-fault was probably continuous, but its outcrop is now interrupted for about 4 miles by a northward extension of the Cruachan " Granite ".

The sunken area is girdled by a discontinuous igneous complex in the form of an irregular ring-dyke (p. 35) of porphyrite merging into " granite ". This is the Fault-Intrusion of Glen Coe—so named from its intimate connection with the Boundary-Fault of the Cauldron-Subsidence ; some portions of it, generally more or less crushed, have been separated under the designation of Early Fault-Intrusion (Figs. 24-26). The Fault-Intrusion rose up around the subsiding block as the latter settled down, but before we can substantiate this statement it is necessary to give a résumé of the evidence upon which it is based. A fuller account has already been published, to which the reader is referred (Clough, Maufe and Bailey 1909) ; and this has been elaborated in several respects in programmes for two road excursions in Glen Coe given on pp. 72, 137.

SUBSIDENCE OF LAVAS

The existence of a cauldron-subsidence is suggested by the compact area occupied by the volcanic series in the heart of the schists, especially as, in many places, the lavas abut against the steep even plane of a bounding fault, and there stop abruptly. This last relation is especially well seen between An t-Sròn (Fig. 20, p. 133) and Dalness. The lavas also almost always show a marginal inward tilt, sometimes amounting to actual inversion (Figs. 20-1, 23-5).

Only very minor outcrops that can possibly be attributed to the Glen Coe volcanic series or its associated sediments occur outside the innermost branch of the Boundary-Fault. These have already been discussed under the heading " Fissure-Fillings or Outliers " (p. 150).

SUBSIDENCE OF SCHISTS

The importance of the subsidence which has preserved the Glen Coe volcanic rocks from erosion is also strikingly illustrated by the distribution of the schists within the downthrown area. The effect of the Gleann Chàrnan branch of the Boundary-Fault is particularly obvious (Sections G and H, Fig. 7, p. 48). Here for a distance of two miles Leven Schists, in what we have called the " cover " position, are thrown down on the north-east against " basement " Glen Coe Quartzite and, for a short distance, against Ballachulish Limestone overlying the latter.

The same juxtapositions are found along the main fault where it crosses Glen Coe further north, though the evidence is somewhat blurred by the unconformable lavas inside the Cauldron, and by widespread invasion by Fault-Intrusion, outside the same. Under the lavas the Loch Achtriochtan phyllites belong to a rather high portion of the Leven Schist " cover ", and are thrown down against external Ballachulish Limestone and " basement " Glen Coe Quartzite. The interest is heightened because the Loch Achtriochtan phyllites have suffered appreciably less regional metamorphism than the rocks against which they are thrown, which is taken to show that the grade of regional metamorphism in this district diminishes upwards (pp. 71, 78-9).

The Ballachulish Limestone of Glen Coe just outside the Cauldron has a continuous outcrop south of the river, where it passes south-eastwards under " cover " Leven Schists between Achnacon farm and the An t-Sròn mass of Fault-Intrusion. It also, north of the river, spreads out to give two extensive outlying patches, one of which reaches up to the watershed in Sgòr nam Fiannaidh. A further representative of these isolated external outcrops occurs immediately north of Meall Dearg (Fig. 23 ; Bailey 1934a, fig. 4, p. 487). Here the limestone is brought by an outer branch of the Boundary-Fault into contact, north-eastwards, with structurally underlying quartzites and mica-schists in " basement " position.

Within the circuit of the Main Boundary-Fault in this same northern district the Ballachulish Limestone, which one would expect to rise northwards from beneath the Loch Achtriochtan phyllites (" cover " Leven Schists) is seen in Coire Càm and Coire Mhorair (Figs. 23,24) .The Coire Càm outcrop is minute, and rests on inverted basement conglomerate belonging to the Glen Coe volcanic series, as indicated by a note in Fig. 23. The Coire Mhorair outcrop is large and easily identified on Sheet 53 and Fig. 24. Closely associated volcanic rocks are in both cases steep, sometimes slightly overturned (Figs. 23-5). Exposures to the north consist of structurally underlying quartzite, mica-schist and flags.

Moreover, contrast of strike is often seen in schists on the two sides of various branches of the Boundary-Fault as illustrated in Figs. 24, 26, 28 ; while the reappearance of Ballachulish Limestone from beneath the volcanic rocks in the Coire an Easain stream of Fig. 29, and of Glen Coe Quartzite in " cap " position in small inliers near Dalness (p. 89) fits in exactly with the general picture of subsidence.

CIRCUMFERENTIAL DETAIL

The evidence so far advanced shows that the volcanic rocks and underlying schists occupy a region of subsidence. It is now necessary to give in outline the proof that the sunken region is bounded by a curving dislocation, and not by straight faults accidentally intersecting. The demonstration depends upon the possibility of actually tracing the Boundary-Fault, and this has been effected with great precision, thanks to excellent exposures. The task is made easier by the fact that the fault, or the main fault where there are branches, serves as the inner boundary of the ring-complex known as the Main Fault-Intrusion. Only three or four minute crops of this Fault-Intrusion are known within the circuit of the innermost branch of the Boundary-Fault, whereas outside, for a distance of about a mile, there are numberless masses of the intrusion ; not only so, but wherever an individual mass is in contact with the fault it presents to it a smooth well-defined margin, though elsewhere its boundaries may be highly irregular. This feature is abundantly clear in the one-inch map, and in Figs. 19-21, 23-8.

The contact-metamorphism induced by the Main Fault-Intrusion is similarly restricted, so that the lavas and schists within the Cauldron-Subsidence have escaped almost untouched, with the exception of the rocks in the neighbourhood of the large offshoot of the Cruachan " Granite ". In correlation with this phenomenon the Main Fault-Intrusion invariably shows chilled margins to the corresponding branch of the Boundary-Fault wherever the two are seen in contact from Dalness in Glen Etive right round to Meall a' Bhùiridh (Fig. 29). Along its external boundaries, on the other hand, while chilling is not uncommon, it is anything but universal.

A very brief statement of the phenomena encountered along the course of the fault is given below. C. T. C., H. B. M., E. B. B.

South of Dalness.—The Boundary-Fault is in two branches south of Dalness. An inner fault is well seen on the hillside between 1100 and 1200 yards south-east of the house. It inclines steeply towards the region of subsidence, and separates quartzite on the south-west from rocks of the volcanic series on the north-east. A highly sheared band intervenes ; and a thin streak of nearly vertical black flinty crush-rock traversing the rhyolite lavas close to the dividing plane shows incipient crystallisation due to hornfelsing (S 11464). A little farther up the hill a grey porphyrite, belonging to the Fault-Intrusion complex, extends along the Fault for a distance of about a third of a mile. Its north-eastern margin is chilled and nearly straight, while its south-western margin is distinctly less regular.

On the west flank of Beinn Ceitlein the outer branch of the fault can be recognised by evident discordance of the schists on its two sides. It is inclined north-westwards or westwards often at comparatively low angles of about 50°. Like the inner branch it is locally accompanied by grey porphyrite acting the part of Fault-Intrusion. Further discussion is given on p. 88.

The two branches converge south-east of Dalness.

In chapter xviii it is shown that the Fault-Intrusion south of Dalness is contact-altered. There can be no doubt that the effect is due to the Cruachan " Granite ". The two intrusions are seen together a third of a mile S.S.E. of Dalness, where abundant red " granite " strings project from the surface of the porphyrite. C. T. C.

Dalness to Glen Coe.—The Boundary-Fault is again in two branches. The inner is clearly marked in this region as the limit of the volcanic rocks. It is further distinguished by the presence of a loose fault-breccia which weathers out, yielding a more or less decided hollow (Fig. 20, p. 133). The fault-plane inclines normally at about 70°. Almost along its whole course one finds Fault-Intrusion—pink and grey " granite " and porphyrite—swelling to a large mass in An t-Sròn, and everywhere presenting a smooth chilled edge (S 10309) to the fault. The loose fault-breccia involves this chilled edge, and is thus evidently due to a recurrence of movement along the old line of weakness. In keeping with this one finds the N.E. porphyrite dykes, of considerably later date than the Fault-Intrusion, thoroughly broken where they cross the line of the Boundary-Fault. Where the crush-rock in the fault is of a compact nature, as south of Dalness, at Stob Mhic Mhartuin, and in the Càm Ghleann, the N.E. dykes cross without suffering brecciation. The crushing north-west of Dalness affects even a basalt dyke, presumably of Tertiary age.

The outer branch of the Boundary-Fault runs along Gleann Chàrnan. It is recognisable by its effect upon the schists, and its position is further marked by a

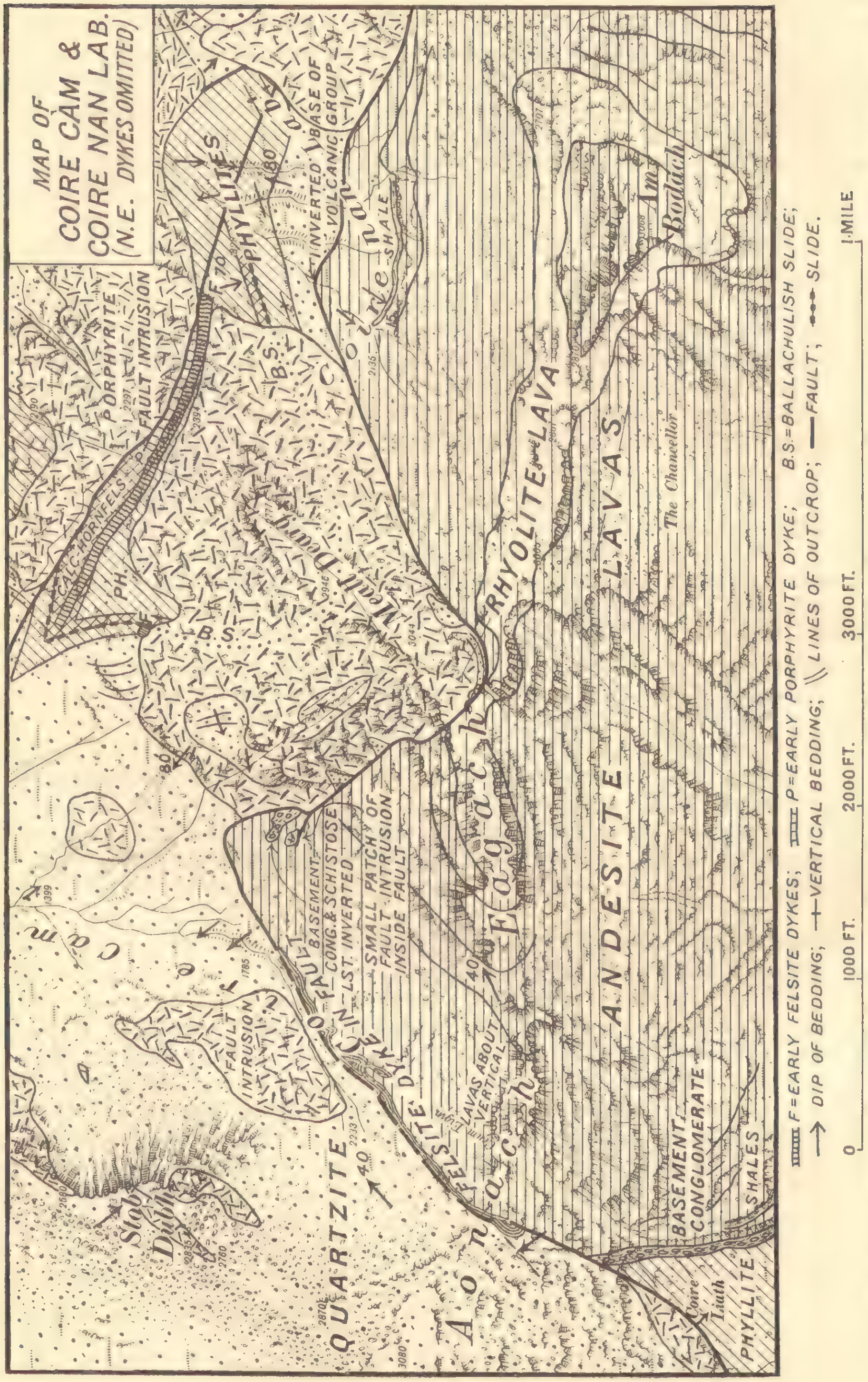


FIG. 23. Map of Coire Càm and Coire nan Lab. North-east dykes omitted. (The Fault-Intrusion is chilled at its contact with the early dykes north of Meall Dearg)

line of loose crush-rock. A tongue of Fault-Intrusion extends along its outer side with the usual relationship. H. K., H. B. M.

Crossing Glen Coe.—The reader is once more referred to the road excursions, pp. 72, 137.

North of Glen Coe.—The evidence for the Boundary-Fault in its usually double, sinuous course north of Glen Coe is presented in Figs. 23-28. The northern branch, north of Meall Dearg in Fig. 23, was recognised comparatively recently (Bailey 1934a, p. 486) as a result of reinvestigation of the schists (p. 80). All the rest was described in detail in 1909.

From its turning point in Coire Càm to Stob Beinn a' Chrùlaiste near the Glen Coe road, the main or southern branch is inclined outwards, that is towards the north, at angles varying between 70° and 50°. The northern, outer branch, at any rate from Coire Mhorair to Stob Mhic Mhartuin, is similarly inclined, and is of earlier date.

From Loch Achtriochtan to Coire Odhar-mhòr the Fault-Intrusion is mainly represented by pink porphyrite. The " Granitite Fault-Intrusion " distinguished in Fig. 24 is easily separable from the main Fault-Intrusion. The junction of the two is exposed at the base of Sròn Gharbh and is not quite sharp, being marked by a foot or so of hybrid rock (S 13342). Probably the coarser rock is somewhat the later ; its uprise may well have been contemporaneous with that of the main mass of the Cruachan " Granite ".

Numberless intrusions of pink porphyrite belonging to the Fault-Intrusion occur between Garbh Bheinn and Glen Coe, and are particularly interesting for they frequently present unchilled margins. The district has probably been subjected to extensive explosive and pneumatolitic action. On the one hand, the porphyrite is often not only richly charged with xenoliths of baked mica-schist and quartzite, but also loaded with quartz grains separated from the quartzite (p. 219) ; on the other hand, the quartzite, where it retains its individuality, is frequently saturated with pink felspar from the porphyrite. The irregularity of the geology prevents accurate mapping. W. G. Hardie has made a special study of the Garbh Bheinn district and thinks that some very considerable areas of quartzite belong to giant displaced xenoliths (1955).

It has already been pointed out that the alteration of the schists due to the intrusion of the Main Fault-Porphyrite is limited by the main branch of the Boundary-Fault. This is particularly well illustrated in Coire Mhorair and the ridge to the east (Fig. 24 ; and Bailey 1934a, fig. 4 and p. 505). Inside the inner, main branch of the Fault, well bedded, pure white quartzite (Glen Coe or older) dips steeply beneath thin black schists (Ballachulish Slates), and these under calcareous schists and limestones (Ballachulish Limestone), the whole showing no trace of contact-alteration. Outside, quartzite and Eilde Flags are encountered with obscure bedding and local well-marked reddening. An additional feature in these outer rocks is that they are pierced by many irregular intrusions of pink felsite, which are quite unknown on the downthrow side of the inner fault. One felsite is intruded by a vein of flinty crush-rock.

The most interesting single exposure of the Glen Coe Fault is exhibited in Stob Mhic Mhartuin (Pl. IX and Fig. 27). The map (Fig. 26) shows how readily two branches of the Fault can be recognised by paying attention to the nature and strike of the schists which they traverse. What is not apparent on the map is

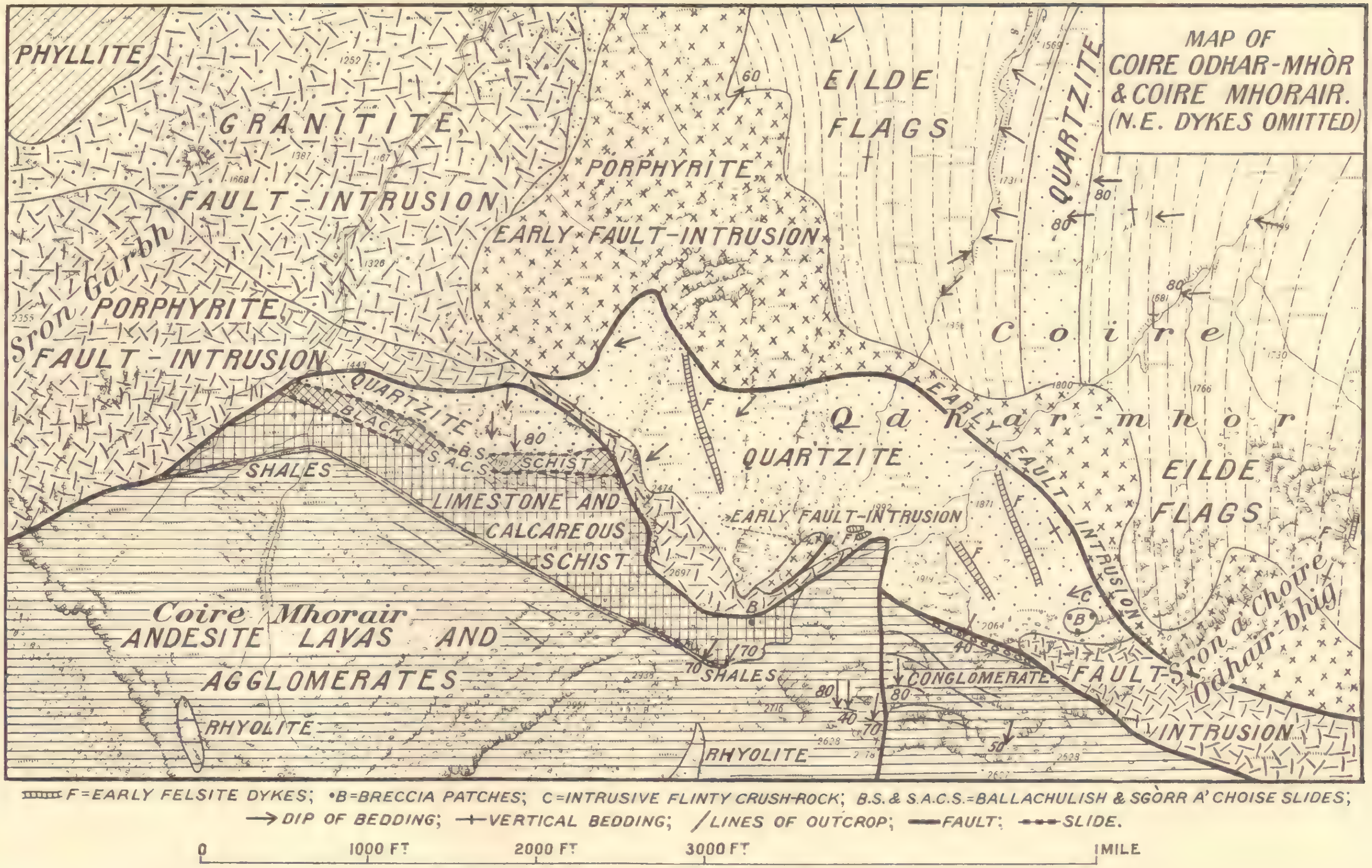


FIG. 24. Map of Coire Mhorair and Coire Odhar-mhòr

the amount of disturbance and reddening characteristic of the schists between the two branches of the Fault and for about a third of a mile to the north-east.

The two branches of the Fault are accompanied outside by grey Fault-Porphyrites, but the porphyrites in the two cases are not identical. The inner one can easily be recognised as the Main Fault-Intrusion of Glen Coe ; the outer is Early Fault-Intrusion, a rather different rock, distinguished alike by original characters, and by its moved, broken, and baked condition. Traced westwards into Sròn a' Choire Odhair-bhig (Fig. 24) the inner, Main Intrusion occupies the whole distance between the two branches of the Fault. To the north it exhibits a chilled undisturbed edge against a banded flinty crush-rock (S 12935, see below), which on its other side passes imperceptibly into the strongly sheared margin (S 12934) of the outer, Early Porphyrite (S 12933). No more convincing evidence could be desired : the outer Fault-Intrusion is of comparatively early date, and has suffered from a recrudescence of shearing posterior to its consolidation—shearing which has not affected its later neighbour. It may be added that the Main Fault-Intrusion hereabouts chills at all contacts, and not merely at the Main Boundary-Fault, thus departing from the rule followed when the Main Fault-Intrusion assumes either "granitic" or permeative crystallisation. E. B. B.

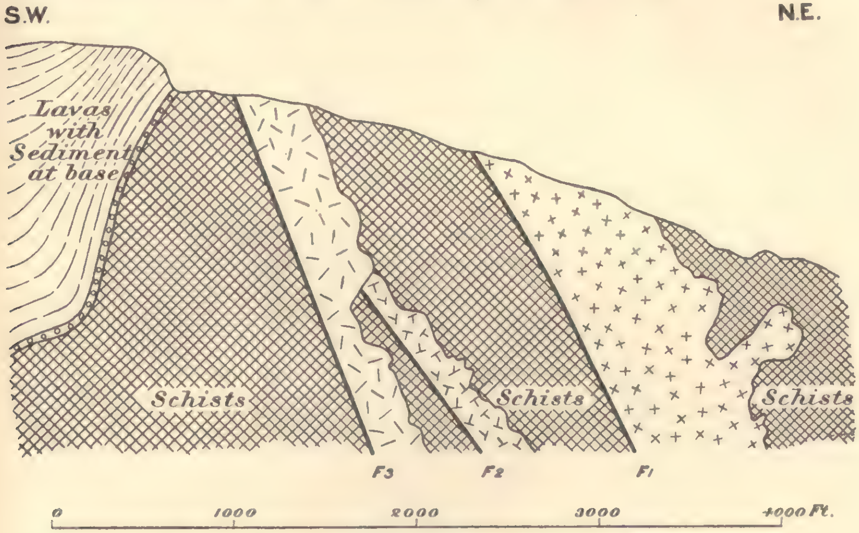


FIG. 25. Section through ridge W. of Coire Odhar-mhòr

F1 and F2 Early Boundary-Faults accompanied by Early Fault-Intrusions. F3 Main Boundary-Fault with Main Fault-Intrusion

Before quitting the Stob Mhic Mhartuin section, special attention must be drawn to the shearing along the main fault, illustrated in Pl. IX and Fig. 27. The rocks of the low frontal cliff of the Stob are well bedded quartzites lying on the downthrow side of the inner, south-west fault of Fig. 26. They are traversed by minor planes of movement crossing their bedding and occupied by a few inches of hard white rock composed of ground-up quartzite. Along the main line of movement the bedded quartzites are truncated by a zone of similar white crush-rock (S 12329) two feet thick. Beyond this, long tongues of the white crush-rock begin to be isolated in a darker matrix with obvious flow-structure ; then these tongues disintegrate, and the proportion of fluxional matrix rapidly increases. The fluxion-breccia which results is a foot wide, and next to it is a layer, an inch thick, of black flinty crush-rock (S 12332). C. T. C., E. B. B.

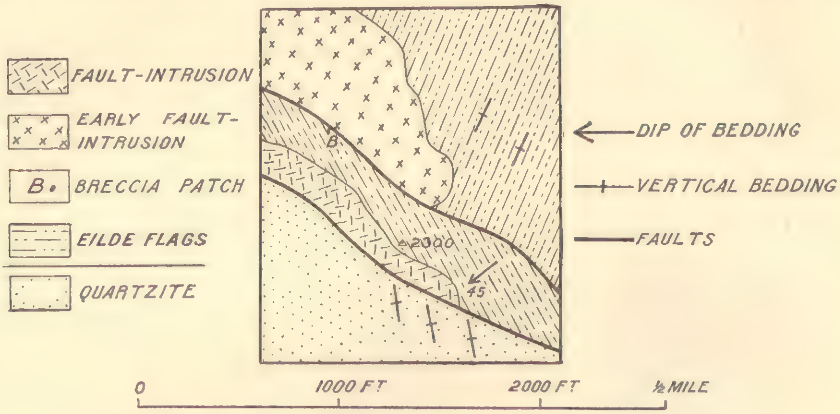


FIG. 26. Map of Stob Mhic Mhartuin. North-east dykes omitted

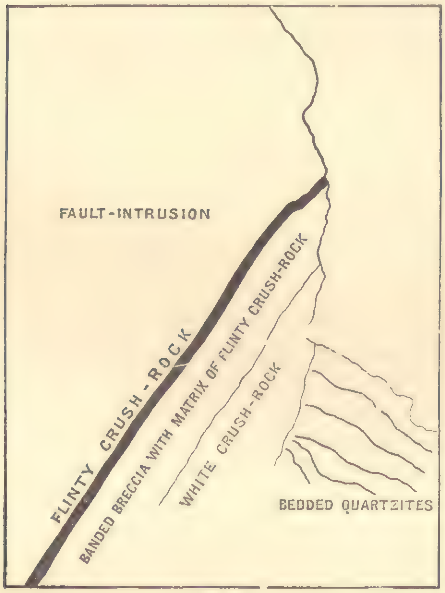
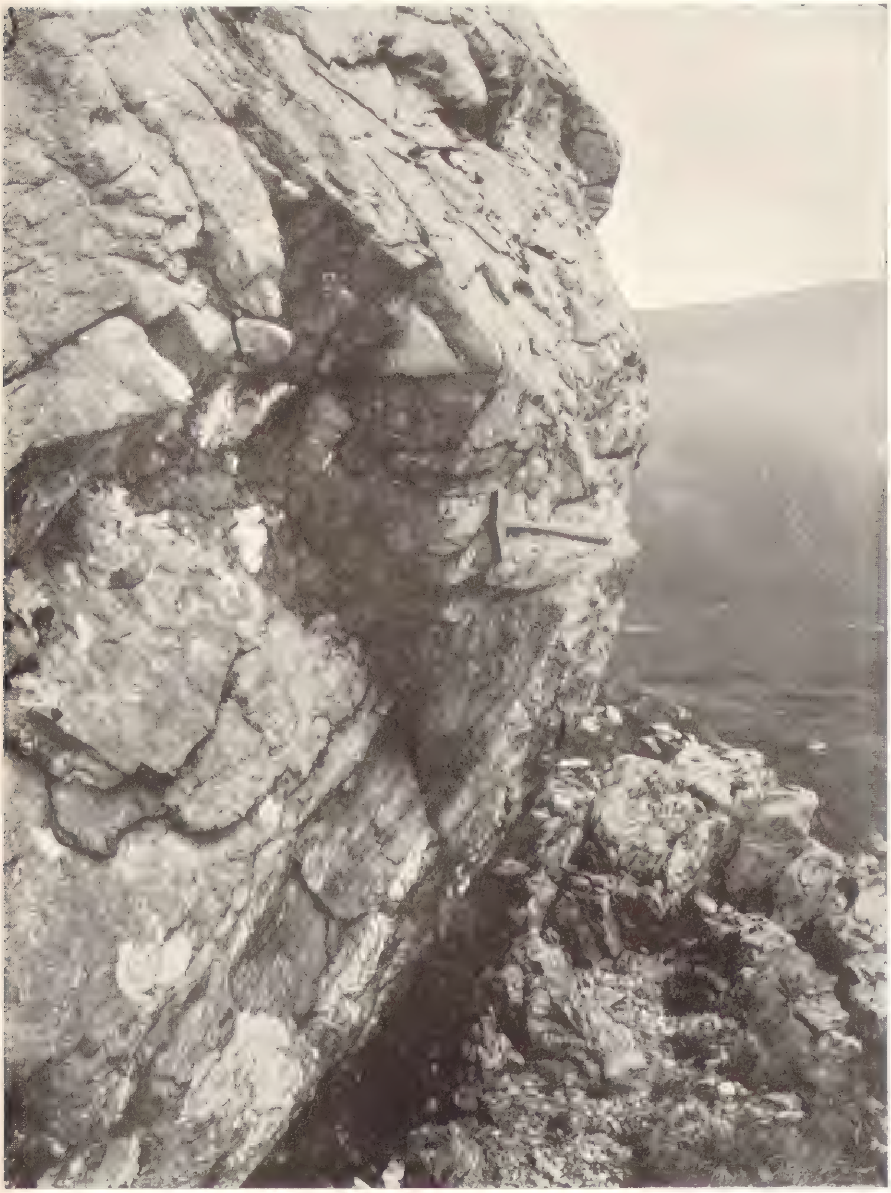


FIG. 27. Diagram explaining Pl. IX

We may preface further detail regarding this type section by noting that much has been written on the subject of flinty crush-rocks ; and the reader should consult the paper on the Cauldron-Subsidence (Clough, Maufe and Bailey 1909, pp. 629-31, etc.) to learn the part played by Clough and Holland in its early elucidation. Since then the most important publications have been by :



GLEN COE FAULT, STOB MHIC MHARTUIN

(1) Termier and Boussac (1911), writing on mylonites in the Alps.
(2) Quensel (1916), discussing mylonites in regard to Sweden.
(3) Shand in his account (1917) of " pseudotachylite " at Parys Mountain, Orange Free State.
(4) Bowen and Aurousseau in a discussion (1923) of artificial examples of flinty crush-rock accidentally produced in boring for oil.
(5) Jehu and Craig in descriptions (1923-4) of a great flinty crush-belt in the Outer Hebrides discovered by Dougal (*cf.* 1928).
(6) Waters and Campbell (1935) in relation to the San Andreas Fault, California.

Flinty crush-rock is an exceptional accompaniment of faulting. In fact, one of its peculiarities is narrow localisation in time and space. Thus flinty crush-rock is scarcely known in Britain away from Cheviot, Glen Coe, Ben Nevis and the North-West Highlands. In the three former it is of Devonian age ; in the latter Pre-Cambrian. In all except Ben Nevis it was first recognised by Clough. So far as Cheviot, Glen Coe and Ben Nevis are concerned it might still be unheard of except for Clough ; but in the North-West Highlands, especially the Outer Hebrides, it is conspicuous (one can sense its presence in Macculloch's descriptions) ; and it must certainly have been investigated ere now without Clough's initiative. As regards scarcity in other settings one must remember that Clough worked in many districts without discovering any trace. It is also worth noting that, whereas flinty crush-rock at Cheviot, Glen Coe and Ben Nevis is linked with volcanic activity, in the North-West Highlands it is not.

It is widely, but not universally, agreed by investigators in different regions of the world that flinty crush-rock has suffered partial fusion by frictional heat. The following common features can be illustrated by examples from Glen Coe :

(1) Flinty crush-rock has definite association with faulting, *e.g.* it lines the early and main branches of the Boundary-Fault of Glen Coe, and also the Boundary-Fault at Ben Nevis.
(2) Where found along faults it is apt to provide small irregular intrusive veins cutting neighbouring rocks, *e.g.* veins (S 12333, 13929) cutting a crag of quartzite at locality (c) west of Sròn a' Choire Odhair-bhig in Fig. 24 ; see also (S 13405a).
(3) The flinty or subvitreous lustre immediately suggests glass, though abundance of debris makes it difficult to establish this interpretation under the microscope.
(4) Almost all districts studied furnish occasional examples of micro-crystallisation of a type that seems to require previous melting, *e.g.* in (S 12933), derived from crushing Early Fault-Porphyrite, there is detectable microtrachytic texture affecting microlites that have probably been hornblende and felspar.

With this background let us concentrate upon the one feature in which Glen Coe, with Ben Nevis, stands by itself, namely the frequent juxtaposition of contemporaneous flinty crush-rock and normal magmatic rock. No better place for its study could be selected than Stob Mhic Mhartuin.

The two feet of " white crush-rock " of Fig. 27 cannot be distinguished in hand-specimen, and scarcely even under the microscope (S 12329), from fine gritty sandstone. There are numberless angular quartz grains up to about half the size of those in the quartzite from which they have been derived ; and this latter is represented by occasional small subangular bits resembling pebbles. Both in the isolated grains and in the compound fragments the quartz shows surprisingly little strain-shadowing. Also mica in the compound fragments is usually unaffected. Quartz in the matrix again abounds, occurring as easily recognisable, smaller and smaller grains ; but mica, once it is freed from the protection of surrounding quartz, soon becomes unidentifiable. The nature of the ultimate base is irresolvable ; but one may note an abundance of extremely fine dark powder. This is a common feature of flinty crush-rocks all over the world. Here the powder may be iron ore derived from destruction of biotite. One feature alone clearly distinguishes (S 12329) from sandstone, namely, a drawn-out area of disintegrating quartzite in which separation of quartz grains, combined with marginal fragmentation of the same and with breaking down of mica crystals, is convincingly displayed. The conditions within this area explain the comparative absence of strain-shadowing in the liberated major quartz grains. The crushing is concentrated on intergranular material.

Specimens (S 12330-1) taken from the one foot of " banded breccia with matrix of flinty crush-rock " of Fig. 27 have much in common with (S 12329) ; but it would be impossible to mistake them for sandstone. They have evidently been broken up at various stages of their development. Their small pebble-like lumps of quartzite frequently show intergranular disintegration accompanied by strain-shadowing of fine-grained shattered material. Much of their matrix is dark ; and dark and pale streaks have frequently been brought by movement into conspicuously transgressive relationships. Some of the dark matrix of (S 12331) has partially cleared in a reticulate pattern with what looks like cryptocrystalline devitrification.

The one-inch " flinty crush-rock " shown in black in Fig. 27 is represented by (S 12332, 13402-3, 13403a)—about a quarter of its total thickness is included in Pl. XI, 3 (p. 211). All these slices reveal virtually complete disappearance of quartzite fragments and continued abundance of unstrained isolated quartz grains, which are set in an evenly banded matrix of paler and darker material. In the paler streaks there is an appearance of microfelsitic devitrification. The three last slices listed above are particularly interesting since they show actual junction of Fault-Porphyrite and flinty crush-rock. Here we see, what can also be recognised in the field, that small, broken felspar xenocrysts are sparsely scattered through much of the flinty crush-rock. They are most numerous close to the porphyrite margin, but some few lie a full centimetre in from the contact. The biggest noted measures only 2 mm whereas the phenocrysts within the adjacent chilled margin of the porphyrite sometimes attain to 3·5 mm. The difference can safely be attributed to fracture. There cannot be any doubt that the crystals have been derived mechanically from the porphyrite, and have not developed *in situ* as porphyroblasts. Every stage of their separation can be studied. They are clearly somewhat broken xenocrysts, though they show no distortion or strain shadows. Where a felspar phenocryst projects from porphyrite into crush-rock we find its exposed side stripped clear of igneous matrix. Well inside the flinty crush-matrix, xenocrysts of iron ore survive along with the felspars, though of course they are rare ; but biotite xenocrysts seem to be limited to the immediate neighbourhood of the junction.

It is noteworthy that, in so far as these slices are concerned, and also at Ben Nevis (S 14044), it is the flinty crush-rock (in molten condition) that has eroded the porphyrite (also molten), and not *vice versa*. Thus while the more resistant solids of the porphyrite are to be found in the crush-rock, even for a centimetre in from the edge, the quartz grains of the crush-rock stop practically abruptly where the felsitic crystallisation of the porphyrite's chilled margin starts. There is, however, a very rapid merge of matrix crystallisation, since subdued felsitic texture extends for a fraction of a millimetre among the quartz grains adjoining the porphyrite. The presence of xenocrysts derived from the porphyrite demonstrates, of course, that a corresponding small amount of porphyrite matrix must have been digested, reaching well into the crush-rock ; and yet the microscope scarcely hints at its presence.

The broken felspar xenocrysts of the flinty crush-rock are too equidimensional to show significant orientation. The felspar and biotite phenocrysts of the porphyrite are in (S 13402) orientated parallel to the flinty crush-margin for at least one centimetre in from the same ; but in (S 13403, 13403a) such orientation is restricted to the immediate neighbourhood of the mutual junction. It is practically certain that the flinty crush-liquid only caught up porphyrite material so long as this latter was a mere film along the fault. Once the porphyrite magma arrived in bulk, the flinty crush-material functioned as a part of its composite chilling margin. (At one point in the exposure chilled porphyrite surrounds a small angular fragment of flinty crush-rock, but such a complication is commonly met with at chilled edges of intrusions.) That the porphyrite should be able to chill in contact with the flinty crush-rock, may at first sight seem anomalous, as the latter almost certainly started considerably the hotter of the two. The explanation is that the very small thickness of the flinty crush-material allowed it to carry only a negligible supply of heat, which was lost rapidly by conduction into the cold down-faulted mass within the cauldron-subsidence.

It is fortunate that we can contrast the margin just described, between contemporaneous Fault-Intrusion and flinty crush-rock, with another margin close at hand where Fault-Intrusion came in contact with flinty crush-rock older than itself. The locality has already been mentioned on the west slope of Sròn a' Choire Odhair-bhig (Fig. 24), where Main Fault-Intrusion chills against flinty crush-rock that affects Early Fault-Intrusion immediately to the north. (The Main Fault-Intrusion is the same as in Fig. 27, but the flinty crush-rock is entirely different). The microscope shows in (S 12935) an absolutely abrupt contact. The first crystallisation of the Main Porphyrite takes the form of a quartzo-felspathic comb-fringe, a small fraction of a millimetre thick, with the teeth of the comb pointing back into the igneous rock except where they fill, crosswise, narrow cracks reaching into the flinty crush-rock.

The flinty crush-rock thus treated lies along the outer, older branch of the Glen Coe Boundary-Fault as traced in Figs. 24, 26. While at the locality just described in Fig. 24 it affects the Early Fault-Porphyrite in contact to the north, further east, north of the 2300-ft summit of Stob Mhic Mhartuin (Fig. 26), it is unaccompanied by any shearing of this intrusion. In fact north of Stob Mhic Mhartuin one finds the same type of contemporaneous association between

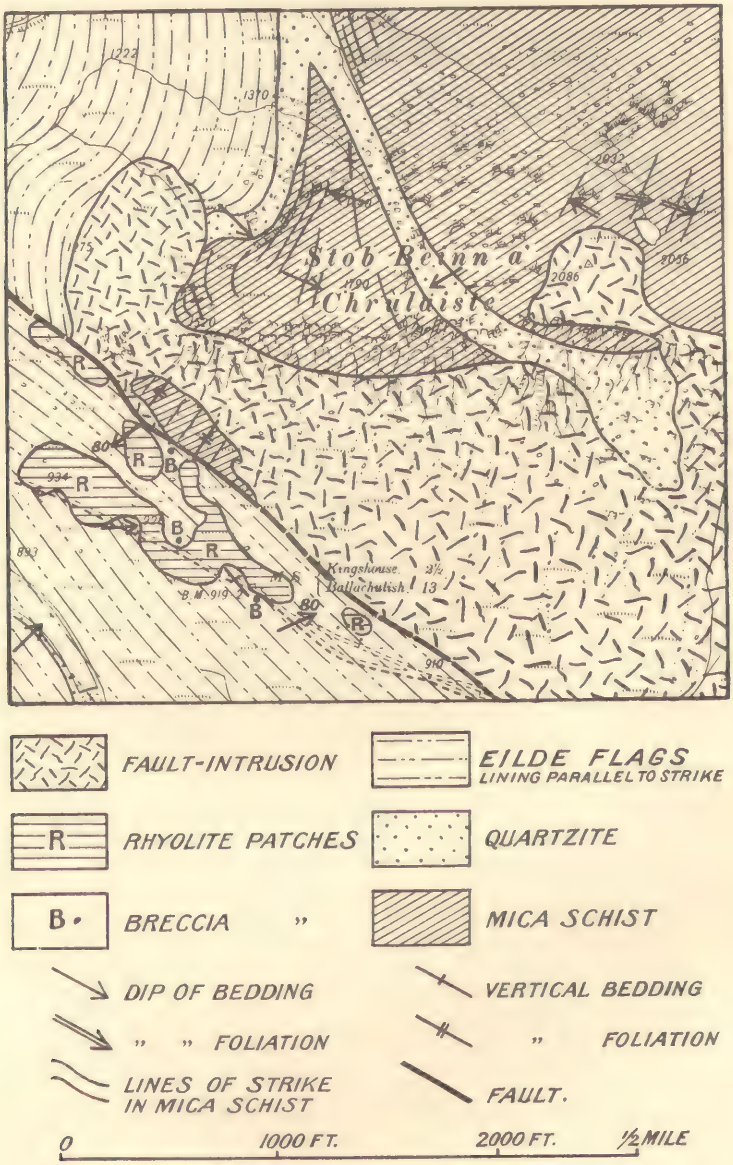


FIG. 28. Map of Stob Beinn a' Chrùlaiste. North-east dykes omitted

Early Fault-Porphyrite and early flinty crush-rock as has been described for the Main Fault-Porphyrite and main flinty crush-rock making the cliff of Pl. IX. The crushing of the Early Fault-Intrusion at Sròn a' Choire Odhair-bhig must be due to a local recurrence of movement.

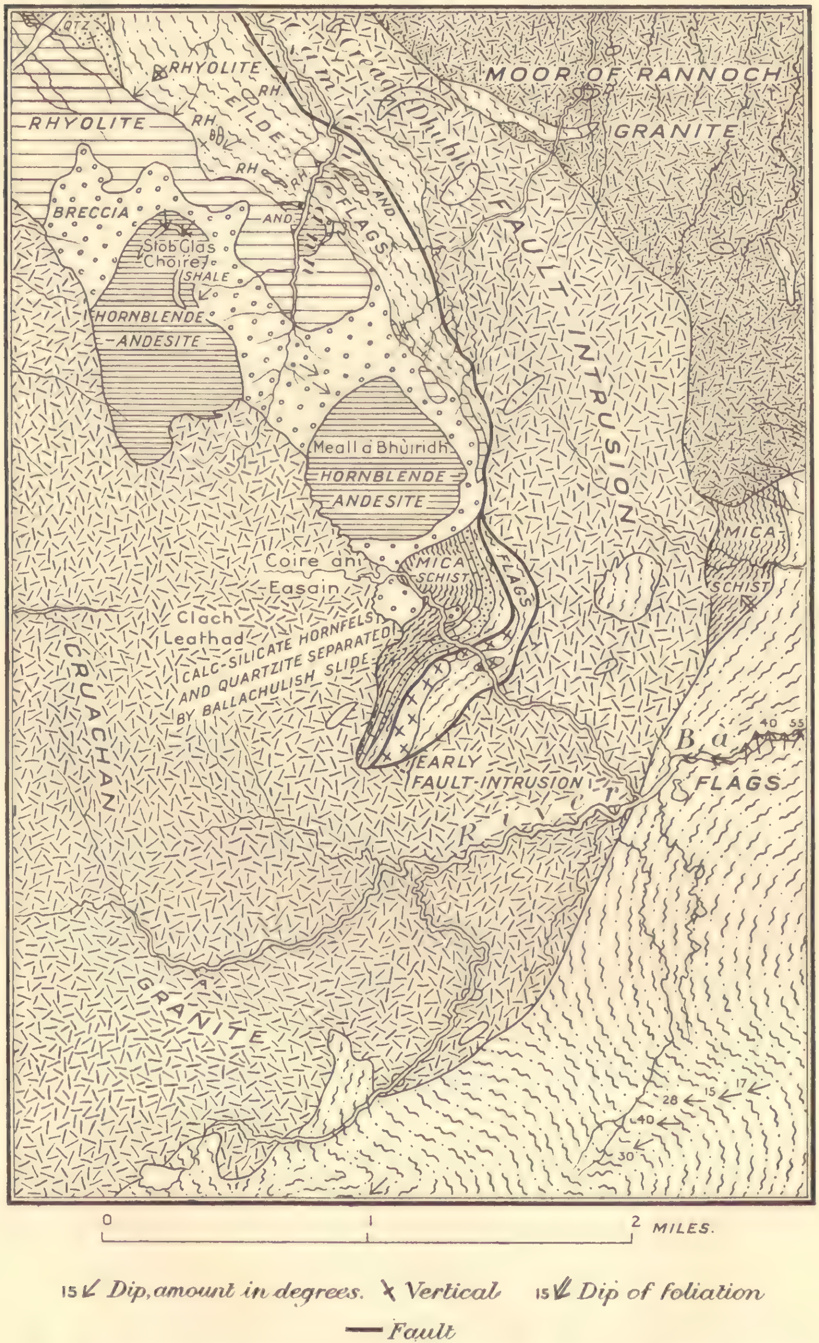


FIG. 29. Map of Càm Ghleann and Coire an Easain. North-east dykes omitted

An excursion to Stob Mhic Mhartuin is the most rewarding that can be taken in regard to the boundary-faults of the Glen Coe cauldron ; and it is hoped that visitors will not damage the best exposures. The most convenient approach is from the Cnoc nam Bocan signpost on the Glen Coe road (Fig. 22), where cars or buses may be parked in an extensive rhyolite quarry (p. 142). From here it is easy and interesting to traverse the hillside north-westwards, following the base of the volcanic series, until on a level with Stob Mhic Mhartuin which stands out a prominent, unmistakable little crag. From Stob Mhic Mhartuin it is a simple matter to continue along the crest of the summit ridge to visit Coire Odhar-mhòr and Coire Mhorair of Fig. 24.

The Stob Beinn a' Chrùlaiste evidence further east is sufficiently set out in Fig. 28. In this sketch-map only the old road is shown, but the new road lies a few yards to the south-west. The patches of rhyolite and breccia between the Boundary-Fault and the road have already been discussed (p. 151). E. B. B.

Càm Ghleann and Coire an Easain.—After leaving Stob Beinn a' Chrùlaiste, the Boundary-Fault is obscured by moraine until Càm Ghleann is reached (Fig. 29). It is easy, however, to trace a continuous broad band of Fault-Intrusion between the two localities. In Stob Beinn a' Chrùlaiste the intrusion is a coarse grey porphyrite, but it rapidly merges into grey " granite " when followed south-eastwards. It may be mentioned here that the Fault-Intrusion cuts, and encloses fragments of, the Moor of Rannoch "Granite ". At the same time the junction may be much obscured by interaction. Thus a narrow hybrid zone (S 12752-3 in the River Coupall, 12747-8 in the Etive) may intervene between acid Moor of Rannoch " Granite " (S 12749-50) and intermediate Fault-Intrusion (S 9129, 12502-3).

In Càm Ghleann, the fault plane, inclining outwards, is very clearly exposed in the river bed, where it is marked by a zone of flinty crush-rock, against which the Fault-Intrusion chills. In Meall a' Bhùiridh the Fault can once more be accurately located, and again the Fault-Intrusion is found to be chilled at its contact.

The Fault-Intrusion continues southward from Meall a' Bhùiridh, but before long loses its main distinguishing characteristic, and ceases to show a chilled interior margin, although probably still bounded on its inner side by the fault plane. Beyond this it joins the Cruachan " Granite " at the point where the latter sweeps across the fault into the sunken mass within. A rather sudden change from grey to pink " granite " occurs in the crags north of the stream from Coire an Easain.

The Early Fault-Intrusion shown in Fig. 29 is a grey diorite. It presents a chilled edge against an inner branch of the Fault. The interesting feature of this chilled edge is that it shows evidence of what may be contemporaneous shearing—but see p. 174. The phenocrysts are strongly deformed, especially the ferromagnesian elements, which are drawn out into filmy aggregates of biotite. The intrusion shows no evidence of crushing following its consolidation, but its early date is indicated by its truncation by the main Fault-Intrusion.

Turning back we may note that a small mass of diorite, of similar type to the Early Fault-Intrusion just described, is found a little distance within the Boundary-Fault in Càm Ghleann, where Fig. 29 shows it without ornament at the bend of the stream. It rests with an even base upon a gently inclined plane marked by intense shearing of the underlying schists. E. B. B., G. W. G.

CONCLUSIONS

In dealing with the relations of the crush-rock and the Fault-Intrusion as exposed in Stob Mhic Mhartuin, it was pointed out that the intrusion must have risen along the fault while subsidence was still proceeding. The same conclusion can be established on quite other grounds. As the Fault-Intrusion is constantly chilled against the fault plane, its introduction did not antedate the movement of subsidence. Equally certainly it cannot have been later, or else there would have been no cause to prevent the intrusion entering the schists inside the fault, for outside it has pierced these same schists with the greatest possible freedom. The faulting and intrusion were therefore contemporaneous ; wherever the magma rising up the fault fissure trespassed into the subsiding mass it was carried down. Moreover, cold rocks were descending from above, against which the Fault-Intrusion chilled. It did not penetrate them freely. It did not even heat them sufficiently to produce appreciable contact-alteration.

The perfection of the adjustment is surprising. One would scarcely have expected to find the fault surface smooth and unbroken in contact with the Fault-Intrusion, and yet this is a phenomenon repeated in numberless exposures. An explanation has been offered based upon Daly's (1908) conception of stoping. The Fault-Intrusion may have worked its way upward largely by stoping, for it is extraordinarily full of xenoliths. The solid schists, at any rate, must have broken along numerous structural planes of weakness, with a tendency to sink as fragments into the intrusion. The fault plane, as the predominant plane of weakness, would in the process be preferentially stripped clean and bare.

C. T. C., H. B. M., E. B. B.

Even if we admit as probable important small-scale stoping, it is unnecessary to suppose that the abundant xenoliths in the Fault-Intrusion have everywhere suffered net depression. They may often have been carried upwards farther than they have sunk. It has been pointed out (p. 76) that, on the north side of Glen Coe, calc-silicate-hornfels (Ballachulish Limestone) has functioned as an impermeable layer, beneath which Glen Coe Quartzite, in " basement " position, has been riddled with Fault-Intrusion ; while, on the south side of the glen, in An t-Sròn, the same calc-silicate-hornfels has been disrupted by the Fault-Intrusion, which has risen on a large scale into " cover " Leven Schists. Now the Fault-Intrusion of An t-Sròn is strikingly rich in xenoliths of Glen Coe Quartzite. Maufe thought that these had sunk from the " cap " position seen to the south in Beinn Maol Chaluim ; but it seems certain that " cap " quartzite had been largely eroded from the An t-Sròn area before the Fault-Intrusion rose into position, since just across the fault pre-intrusion lavas rest directly on Loch Achtriochtan phyllites (Leven Schists below the " cap " quartzite position). Accordingly the writer thinks that the An t-Sròn quartzite xenoliths, big and small, have been carried up from the " basement " position. The magma may well have had explosive tendencies, which may have helped it to acquire its wealth of inclusions.

E. B. B.

The occurrence of early branches of the Boundary-Fault, accompanied by Early Fault-Intrusions, distinct in material from the Main Fault-Intrusion, shows that the Cauldron-Subsidence was to some extent completed in stages. On the other hand the frequent development of flinty crush-rock indicates that movement, when movement occurred, was apt to be rapid. That considerable rapidity was sometimes maintained, through thousands of feet of subsidence, is demonstrated by the marked difference of temperature within and without the cauldron as registered in the behaviour of the Fault-Intrusion.

The merging of the Fault-Intrusion with the Cruachan " Granite " on the eastern side of the subsidence probably shows a very close connexion between the two. The Fault-Intrusion is best regarded as an advance guard of the Cruachan " Granite," though portions of it, as at Dalness, had undoubtedly consolidated before the main mass of the " granite " was intruded. The conditions under which the Cruachan " Granite " transgressed the Boundary-Fault and entered the Cauldron-Subsidence are considered in the following chapter.

C. T. C., H. B. M., E. B. B.

The inclination of a ring-fault, such as the Boundary-Fault of the Glen Coe Cauldron-Subsidence, is always a matter of interest from the point of view of geomechanics. It is, however, important to realise that original inclination may sometimes have been modified.

Along the south-west margin of the Glen Coe Cauldron both Clough and Maufe have found the main branch of the Boundary-Fault to be inclined steeply and normally, that is inwards in the direction of downthrow. Maufe records the angle as about 70°.

In the southernmost part of this area, at Beinn Ceitlein, Clough found an exterior branch-fault inclined towards the north-west or west at an angle of about 50°. It is uncertain at present whether this inclination is normal or reversed (p. 89).

No information seems to be available about the inclination of the Gleann Chàrnan branch.

Along the northern and north-eastern margin of the cauldron, many exposures north of the Glen Coe road, and isolated ones in Càm Ghleann and Coire an Easain show all branches of the Boundary-Fault with outward reversed inclinations at angles of from 70° to 50°.

In the southern summit of Bidean nam Bian, seen behind An t-Sròn in Fig. 20, Maufe found the lavas of Groups 1 and 2 dragged up vertically close to the Boundary-Fault. This is what might be expected if, at the time of subsidence, the Boundary-Fault had normal inclination, for the descending mass would press on the inwardly directed slope of external country-rock. A problem, however, is presented when we meet similar marginal uptilting all the way along the northern stretch of the Boundary-Fault from Coire Càm to Coire Odhar-mhòr (Figs. 23-5), in spite of the fact that the fault here has reversed, that is outward inclination.

Various hypotheses may be advanced, for instance :

(1) The fault may have been normal to begin with, and may have been rotated by pressure on its original inward slope during the development of internal subsidence.

(2) The fault may have been normal to begin with, and may have been rotated by subsequent earth-movement unconnected with the Cauldron-Subsidence.

(3) The fault may have been reversed to begin with, and prior to arrival of Fault-Intrusion it may have been kept closed by bending forward of the external country-rock, which, through making frictional contact with the descending internal mass, might lead to marginal deformation.

Attention may be directed to a dynamical interpretation of ring-fractures, advanced by E. M. Anderson (*in* Bailey and others 1924, p. 11 ; Anderson 1936). In this an outward inclination is expected. As shown above, outward inclination of the Glen Coe Boundary-Fault is not universal and, where it occurs, is open to more than one interpretation. At the same time outward inclination has been observed in a number of other ring-fractures elsewhere coupled with interior subsidence.

E. B. B.

CHAPTER XIII

ROCKS OF LOWER OLD RED SANDSTONE AGE
" GRANITE " COMPLEX OF ETIVE

Introduction

We continue to employ the convention that " granite " between inverted commas includes quartz-diorite as well as granite as understood by petrographers. The Etive " Granite " Complex (8, Fig. 18, p. 129) is one of the largest of its kind in Scotland. It reaches from the tributaries of Glen Coe—or from Glen Coe itself if we include the Fault-Intrusion—south-west to the right-angle bend of Loch Etive. Its length is about 18 miles, its breadth about 10. Much the greater part lies in Sheet 45 (Geol.) to the south of Sheet 53. Sheet 45 covers not only Loch Etive, but also Ben Cruachan, Ben Starav and Beinn a' Bhuiridh, names that will recur in the sequel. Kynaston had the privilege of mapping almost the whole complex, and his final descriptions are to be found in the memoirs dealing with Sheet 45 (*in* Kynaston and Hill 1908, chap. viii) and Sheet 53 (*in* Bailey and Maufe 1916, chap. ix), in which he established many of the principal features of the complex.

After Kynaston left for South Africa his mapping in Sheet 53 was completed by colleagues. Thus Clough made a new point in tracing a ring-dyke of granite at Meall Odhar, separated in Fig. 19, p. 132 ; and he was associated with Maufe and the writer in discussion of the complex as a whole in the light of the phenomena of the Cauldron-Subsidence of Glen Coe (1909, pp. 669-675). Much later J. G. C. Anderson re-examined all the evidence in detail, and published what will be for long the standard account (1937a). He made two specially important discoveries :

(1) Clough's Meall Odhar Granite, or an approximate equivalent, reappears to the west at Stob Gaibhre at the southern border of Sheet 53, and between here and Ben Cruachan occupies in irregular fashion roughly half of the area assigned by Kynaston, in a broad sense, to the Cruachan " Granite ".

(2) A crescent " screen " of older, often foliated, rock mapped by Kynaston at Beinn a' Bhuiridh has been definitely proved to consist mainly of altered lavas, attributable to the Lorne traps. Kynaston had recognised lava affinities, but had considered the mass intrusive—probably an early member of the Cruachan suite affected by " movements which accompanied, or immediately preceeded, the intrusion of the enormous mass of the Ben Cruachan granite " (*in* Kynaston and Hill 1908, p. 101).

Anderson also confirmed evidence pointing to gravitational differentiation *in situ* (pp. 169, 170).

If we accept Anderson's correlation between the Stob Gaibhre and Meall Odhar Granites, then the Etive Complex in the main consists of three members, which in order of age are : Cruachan " Granite," in large measure quartz-diorite ; Meall Odhar Granite, the most acid of the three ; and Starav Granite which in the past has sometimes been called after Glen Etive or Black Mount. Taking the complex as a whole the Meall Odhar Granite is of quite subordinate bulk.

The Cruachan " Granite " is older than the north-east dykes of the Etive Swarm (p. 197), the Meall Odhar Granite is older than some, but younger than many others, and probably contemporaneous with one prominent example ; the Starav Granite is younger than almost all. These time-relations were determined by Kynaston for the Cruachan and Starav members of the complex, and by

Clough for the Meall Odhar member at Meall Odhar and by Anderson (1937a, p. 508) further south in Allt Brander (Sheet 45, Geol.). E. B. B.

CRUACHAN " GRANITE "

The Cruachan " Granite," as exposed at the surface, is divisible into two portions, which are confluent, but still more or less distinct. The one extends northwards into the heart of the Glen Coe Cauldron, while the other surrounds, almost completely, the great core of Starav Granite farther south. The rock is medium-grained and carries both biotite and hornblende. In the northern lobe it is prevalently a true pinkish granite. In the southern lobe it is generally a grey quartz-diorite. H. K.

Northern Lobe.—Unusually acid varieties, consisting almost entirely of quartz and felspar, are met with at high altitudes on Aonach Mòr, Clach Leathad, and neighbouring mountains. Drusy cavities are abundant in some places, pointing to a particularly large proportion of occluded gas in the original magma which may quite possibly have been essentially a eutectic residue that collected in the upper part of the boss. H. K., G. W. G.

Anderson after re-examination has written as follows (1937a, p. 504). " The most acid types were found to occur on the long, north-westerly running Aonach Mòr ridge and on a parallel ridge to the south-west, immediately across Coire a' Chaolain. Mineralogically, these are very similar to the Meall Odhar type, but no evidence could be found of intrusive junctions with more basic Cruachan granite exposed on the valley floors and sides ". E. B. B.

The northern lobe invades the volcanic series of Glen Coe. The intrusive behaviour of the " granite " is perfectly certain. Occasional small veins of the " granite " shoot out into the lavas, and fragments of the lavas lie embedded in the " granite ". Along the western slopes of the Sròn na Crèise ridge, between Clach Leathad and Glen Etive, the " granite " is seen cutting across every member of the volcanic series, from the hornblende-andesites at the top, to the rhyolites at the bottom. Everywhere the contacts are remarkably clear, and the alteration of the volcanic rocks easily demonstrable, both in the field and under the microscope. The " granite " veins are often pegmatitic at their margins, and the pegmatite sometimes shows white mica and drusy cavities. H. K.

The junction is sometimes traversed by numerous aplite veins which cut lavas and " granite " alike. G. W. G.

The margin is also generally well defined against the quartzite of Beinn Ceitlein, and is unaccompanied by any marked fringe of minor " granitic " intrusions. Rather more than a mile north-east of the top of Stob Dubh *lit par lit* injection has indeed taken place, but only to a small extent, in a thin band of semipelitic schist lying between the " granite " and the quartzite. Here, in keeping with Kynaston's observation recorded above, the thin " granitic " streaks which have gone along the foliation of the schist are of a distinctly more acid type than the normal " granite ". C. T. C.

The mapping of the " granite " margin in the lava country of Lairig Gartain and the south-east slopes of Buachaille Etive Mòr is mainly due to Grabham, and shows the original roof of the " granite " mass in large measure still preserved from erosion. It is important to note that, although the upper surface of the " granite," thus in part revealed, has a somewhat steeply domed form, the lavas above show no corresponding upheaval. It is safe, therefore, to conclude that the northern lobe of the Cruachan " Granite " is not a laccolith. Further, we know of no section which reveals its base. H. B. M.

Southern Lobe.—Anderson has found that the normal grey hornblende-biotite-quartz-diorite of the southern lobe of the Cruachan intrusion shows a widespread tendency to pass upwards into more acid biotite-granite ; but that the latter is somewhat irregularly distributed, and locally appears at comparatively low levels (1937a, pp. 514, 516). This passage phenomenon must not be confused with the abrupt association with possible Meall Odhar Granite, which will be discussed presently. E. B. B.

The grey quartz-diorite of the southern lobe commonly shows a faint foliation in the orientation of its constituent minerals, and of its fairly abundant, dark, flat inclusions. This foliation is approximately vertical, and runs roughly parallel with the curving outline of the intrusion. Thus in Allt nan Gaoirean the direction varies between E.S.E. and E. by S., while in Glen Ure it has turned round to E.N.E. In all probability the foliation is a flow-structure dating from a late stage in the act of intrusion ; it would be very difficult to believe that the flat inclusions could have been reorientated after complete consolidation of the magma without seriously modifying the igneous texture of the main product. Similar foliation attributable to magmatic pressure is of course well known in plutons of quartz-diorite elsewhere. H. K., E. B. B.

The outer boundary in contact with altered schists is sometimes simple and well defined, but is often, on the other hand, exceedingly complex. In the neighbourhood of Beinn Fhionnlaidh, to the west of Glen Etive, a rock of frequent occurrence consists of an intimate mixture of altered schist and granite, in some parts presenting a profusion of small elongated fragments of schist embedded in a " granitic " matrix. At times, too, where the " granite " is in contact with quartzite, numerous small fragments of quartzite are distributed freely and closely in the marginal portion of the " granite ". The fragments, however, are always angular and sharply defined, and show no signs of partial digestion by the " granitic " magma. The great number of inclusions of all sizes of altered schist in this area forms a striking feature of the Cruachan " Granite ". H. K.

An interesting section occurs on the southern slopes of Glen Ure, where the " granite " comes in contact with a small boss of black and white diorite. The black spots in the diorite are found on microscopic examination to consist of hornblende aggregates, but from the appearance of the rock it is safe to conclude that it was originally an augite-diorite, and that the hornblende is due to contact-alteration. Certainly the diorite is the earlier rock of the two, as it is traversed by veins of " granite " and pegmatite, and, more convincing still, is enclosed as numerous small blocks in the " granite " ; these are well seen on a large, smooth, joint face of the granite, where they weather out as small hollows.

In Sheet 53 the complexity observed at the margin of the southern lobe of the Cruachan " Granite " has comparatively narrow limits, and does not materially affect the value of the boundary line drawn by Kynaston. Comparison of the course of this line and that of the contours shows that the boundary is a somewhat irregular, vertical, curved surface—an observation which agrees well with the vertical course of the foliation already referred to. E. B. B.

Relation to Etive Dyke-Swarm.—The Cruachan " Granite," Glen Coe lavas, and adjoining schists are cut by a very large number of north-east dykes, most of which are porphyrites. Such dykes occur in profusion in the district included in Sheet 53, and, though absent in the Starav Granite, are met with again, equally numerous, in Ben Cruachan itself at the southern end of the Etive Complex (Fig. 18, p. 129). The dykes everywhere present chilled margins to the rocks which they traverse.

H. K.

A point of some interest is that the number of dykes found in the Cruachan " Granite " appears to fall off somewhat rapidly in the central region before the Starav Granite is reached. Much of the ground in which this decrease is suspected is somewhat heavily drift-covered, but Allt nan Gaoirean affords a capital section, and its dykes are, comparatively speaking, rather scarce. It has not been found possible, however, to separate the part of the " granite " which is cut by few dykes from that which is cut by many, and no evidence has been obtained to indicate a difference of age. This subject will be raised once more on p. 201.

H. B. M., E. B. B.

Fine-grained strings of aplite are common within the Cruachan " Granite," and, except in the neighbourhood of the Starav Granite, they all appear to be older than the suite of north-east dykes. It was impossible to make out any rule in regard to their direction.

Veins of pegmatite, aplite, or micro-granite, which are probably connected with the Cruachan " Granite," are only occasionally found at a considerable distance outside its margin. There is an example on the north side of the River Etive, nearly two-thirds of a mile east of Dalness ; the vein here is striking N.N.E., and is at a distance of 200 or 300 yards from the " granite " margin. Another is found about a mile east of Stob Dubh, a little to the west of a later quartz-porphyry dyke.

MEALL ODHAR GRANITE

An arcuate outcrop of very acid, practically binary, granite forms a strip between Stob Dubh and Meall Odhar, and may conveniently be called after the latter mountain. Its presence emphasises the individuality of the two lobes of the Cruachan " Granite " (Fig. 18, p. 129).

For half its course in its type area the Meall Odhar Granite is a marginal intrusion insinuated between the Cruachan " Granite " on the south-west and the schists on the north-east. For the other half of its course, it continues its path south-eastwards without any indication of change, although here it merely separates the two lobes of the Cruachan " Granite ". The arcuate character of its course is sufficiently pronounced to mark it as a ring-dyke. It is generally between 100 and 200 yards broad, and is traceable for about 2 miles.

The Meall Odhar Granite usually weathers into bigger blocks, and disintegrates less readily, than the Cruachan " Granite ". The margins are never chilled, as illustrated in a hand specimen and slice of a contact with Cruachan " Granite " (S 13764). In the south-east it contains rather more biotite than usual, and appears to be divided into three bands, the eastern limits of which, approaching the Starav Granite, are hidden under drift. That it is older than the Starav Granite is shown by its relations to several north-east dykes as described below.

At a point almost a mile south-east from the southern lochan on Beinn Ceitlein there are thin seams in the Meall Odhar Granite, in which the rock occurs in a finely sheared, granulitic condition (S 11498). These seams are individually about half an inch wide, and have been traced for short distances parallel to the general run of the intrusion. They lie about 25 yards in from the north-east margin. C. T. C.

A very acid granite, similar in character to that of Meall Odhar and intermediate in age between the Cruachan and Starav Plutons, occurs six miles to the west at Stob Gaibhre, and continues southwards into Sheet 45. It here lies within the southern lobe of the Cruachan " Granite " ; and, after some interruptions, it forms, 10 miles farther to the south, " the topmost portions of Ben Cruachan and of many of the neighbouring hills " (Kynaston *in* Kynaston and Hill 1908, p. 84). In Kynaston's opinion this pink granite " may sometimes be seen to pass imperceptibly into the normal grey granite [*cf.* p. 170], or to occur in fairly well defined bands and patches ". Anderson is more precise and claims the Stob Gaibhre granite and its southward continuation " as a later intrusion . . . demarcated by sharp junctions " (1937a, p. 492) ; and he correlates it with Clough's Meall Odhar Granite. He also thinks that much of it occurs as a very irregular, lowly inclined sheet capping the Cruachan " Granite ". The shape of an irregular intrusion is notoriously difficult to determine, and it seems possible that this particular intrusion may have burst up from below, and that it tends to make high ground merely because it is specially resistant to weathering—at the same time Anderson's interpretation may very well be correct.

Relation to Etive Dyke-Swarm.—It was during an early stage in the phase of dyke injection referred to in connection with the Cruachan " Granite " that the Meall Odhar Granite, at any rate of the type exposure, rose into position. The majority of the north-east porphyrite dykes, that come in contact, cross it ; but some are cut by it. Veins of the granite are seen, for instance, in a north-east dyke, 930 yards south-east of the south lochan on Beinn Ceitlein. This dyke is of composite character, for while the outer portions are of one type (S 11496), the central, later part is slightly darker and more basic ; but the granitic strings go into both varieties. The outer part is seen on microscopic examination to have suffered contact-alteration, which is most clearly manifested in the peculiar clouded character of many of the felspars.

About 200 yards further east, where quartzite gives place to Cruachan " Granite " on the northern side of the Meall Odhar intrusion, strings of the latter again cut porphyrite dykes. In the same locality other small intrusions of the Meall Odhar Granite, in an uncrushed condition, occupy lines of fault which slightly displace various thin aplitic veins belonging to the Cruachan " Granite ".

A little further south-east, about 1333 yards south of the above-mentioned lochan, narrow bands of pegmatite traverse the Meall Odhar Granite and the Cruachan " Granite " alike ; but they may be genetically connected with the former. About 566 yards south-east of the same lochan strings of aplite and pegmatite are abundant in the quartzite on the north-east side of the Meall Odhar Granite, and have probably originated from it.

It has already been mentioned that Anderson has found evidence further south in Allt Brander (Sheet 45) of dykes which are earlier than what is taken, close at hand, to be the local representative of the Meall Odhar Granite. " Two north-north-easterly dykes," he says, " are cut by veins of acid granite and under the microscope show contact-alteration " (1937a, p. 508).

While earlier than some, and later than others, of the great Etive Swarm of north-east dykes, there is reason to believe that the Meall Odhar Granite is contemporaneous with a quartz-porphyry dyke which has been followed for 8 miles towards the north-east until lost sight of a mile north of Beinn a' Chrùlaiste. The two are not continuous since the quartz-porphyry dyke comes to an end 300 yards north of the main margin of the aplitic granite. For the last 200 yards of its course the dyke has been running due south. Turning to the east at 40 yards distance we find another dyke (S 11499) starting just as suddenly as its neighbour stopped. In composition, texture, width, and direction the two dykes agree, though the specimen quoted happens to be granitic ; and there can be little doubt that they are in underground connection. The more easterly dyke can be traced southwards until it seems finally to coalesce with the Meall Odhar Granite, the texture of which it rather rapidly assumes. C. T. C.

The phenomenon just described of a dyke ceasing at some particular point merely to make a fresh start on a parallel line a short distance to one side is of course quite familiar. In fact the quartz-porphyry dyke dealt with in the preceding paragraph furnishes another clear example of the same kind about a mile south-west of Stob Dearg. G. W. G.

STARAV GRANITE

Only the northern edge of the Starav Granite is included in Sheet 53. The mass consists of pink quartzose granite, coarser in texture and more acid than the normal Cruachan " Granite " ; it is further characterised by a marginal zone with large porphyritic felspars, both pink and white. Scenically the Starav Granite is remarkable for the nakedness of its rock slopes. H. K.

Kynaston did not attempt to map the boundary between non-porphyritic interior and porphyritic margin, for there is a gradual transition spread over a quarter of a mile. Anderson by drawing an approximate line (1937a, fig. 2) found that the non-porphyritic interior lies well to the north-east of the centre of the Starav Pluton. He showed that the width of the porphyritic edge varies from half a mile in Sheet 53 to 3½ miles in Sheet 45. A similar asymmetry holds in the placing of the Starav Pluton in relation to the Cruachan Pluton. E. B. B.

The margin of the Starav Granite is very simple and approximately vertical.
H. K., H. B. M., E. B. B.

Relation to Etive Dyke-Swarm.—Before Kynaston left the Scottish Survey he had raised the question whether the Starav Granite might not be later than the majority of the great suite of north-east porphyrite dykes which cut the Cruachan " Granite," and in many cases the Meall Odhar Granite too. This question has been answered in the affirmative: it is now considered that the Starav Granite is later than most, if not all, of these dykes. Before we arrived at this conclusion we revisited several exposures. The results have been already published (Clough, Maufe and Bailey 1909, p.641), and accordingly, so far as they are concerned with localities in Sheet 45 (Geol.), they will only be dealt with in very brief abstract in the present account.

A N.N.E. lamprophyre dyke cuts across the junction of the Starav and Cruachan Granites, and is chilled against both of them, in the bed of the River Kinglass (Sheet 45). It differs petrographically from the dykes of the great Etive Swarm, in containing purple augite, and in other characters (S 14189). It was at the time the only dyke known to us in the Starav Granite which could possibly be referred to this suite. Anderson has since examined another possible example, a 13-ft microdiorite in the River Liver (Sheet 45). He accepts both instances as very late members of the Etive Swarm and compares them with three very late members of the Ben Nevis Swarm, which cut the Inner "Granite" of Ben Nevis (1937a, p. 507). It is difficult to accept this conclusion in regard to (S 14189).

It has been pointed out that there is apparently a falling off in the number of dykes cutting the Cruachan "Granite" before the Starav Granite is reached; but various sections show that this does not account for the absence of dykes in the latter. The junction of the two granites is exposed for over a quarter of a mile in Allt nan Gaoirean, and whereas five dykes cut the Cruachan "Granite," none cuts the Starav. Moreover, of these five dykes, four are traversed by aplite veins. The only feature which renders this section in the least inconclusive is the presence of strong shearing along the junction of the two "granites".

Half a mile upstream from the point at which the Starav Granite and the Allt nan Gaoirean part company, two more porphyrite dykes are met with, both traversed by aplite veins. These two dykes lie between a quarter and a third of a mile outside the margin of the Starav Granite; beyond this range no instance is known of a porphyrite dyke cut by aplite, although, as already stated, the reverse relation is common. The inference is justified then that the aplite veins where they cut the porphyrite dykes have emanated from the neighbouring Starav Granite.

H. B. M., E. B. B.

Similar evidence is afforded south-east of Meall Odhar in Allt Dochard (Sheet 45), which flows obliquely across the junction line. Dykes, unfortunately not shown on the one-inch map, are here abundant in the Cruachan "Granite" quite near to the Starav margin, while they are absent in the latter intrusion where hypabyssal texture, these dykes are traversed, in common with the Cruachan it in turn forms the bed of the stream. Although they consolidated with typical "Granite," by numerous aplite veins. In this case the margin of the Starav Granite is only 200 yards away.

E. B. B.

The field evidence is corroborated by microscopic study of the dykes. At any rate one of those taken from the contact in Allt nan Gaoirean shows evident contact-alteration (S 14178), and so also do two collected in Allt Dochard (S 14182-3). The same phenomenon was observed in another dyke (S 13762) which cuts the little bit of Cruachan "Granite" exposed in Allt Ceitlein, close to the edge of the Starav mass.

H. B. M.

Another feature of the porphyrite dykes is confined to the neighbourhood of the Starav Granite. A very large proportion of the dykes in Allt Dochard are foliated, especially in their chilled margins. Undoubtedly the structure in this case is due to movement after consolidation, probably under conditions of high temperature afforded by the proximity of the Starav Granite. The direction of the foliation is irregular, and it may make any angle up to 45° with the alignment of a dyke. The structure has affected the phenocrysts, especially the ferromagnesian minerals, which are drawn out into long lenticles. It is generally traceable right up to the dyke margins, but is only doubtfully recognisable in the massive Cruachan "Granite" outside. This immunity of the Cruachan "Granite" does not seem to hold along the south-eastern margin of the Starav Boss, six miles further south-west. Here Kynaston reports that "in many parts of Glen Kinglass, especially about Acharn, the Cruachan granite assumes a well-marked foliated or gneissic structure close to the margin of the coarser, more acid type" (*in* Kynaston and Hill 1908, p.86).

Foliation was also noticed in the Allt Ceitlein dyke, and in three of the dykes in Allt nan Gaoirean. One of these latter was practically in contact with the Starav Granite, the other two at distances of about a third and two-thirds of a mile respectively from its margin. It is important to note that the foliation of the dykes is a quite distinct phenomenon from the widespread, slight, protoclastic foliation of the Cruachan " Granite," which has already been alluded to in Allt nan Gaoirean. The foliation seen in the " granite " runs very steadily east-south-east in this district, whereas that of one of the dykes, for which a record was taken, is east and west, and of another east-north-east. E. B. B.

Other examples, from a district in which the great majority of the dykes are unaffected, occur about a mile S.S.E. of the Ordnance Station, 1731 ft, on Beinn Ceitlein, that is, two-thirds of a mile from the edge of the Starav Granite. Here three thin parallel N.N.E. lamprophyre dykes of somewhat abnormal type (S 11471, 11472) show indications of shearing, while no corresponding shearing was detected in the " granite " at their sides. The shearing crosses one dyke diagonally in a N.W. or N.N.W. direction, but close to the side becomes nearly parallel with it. The dykes cut various veins of aplite and pegmatite as well as granite.

Some rather similar sheared dykes also occur in the Meall Odhar Granite, and enclose pieces of it at a locality about 800 yards south-east by south from the lochan on the south end of Beinn Ceitlein, but they are never much more than a foot thick. They show changes in direction, but strike on the average about E.N.E. This locality lies about half a mile outside the Starav Granite. C. T. C.

ALLT BUIDHE FAULT

The fault shown in Pl. IV crossing Allt Buidhe in Sheet 45 and continuing thence north-north-east to Glen Ure in Sheet 53 throws the Ballachulish Core down towards the Cruachan (plus Meall Odhar) Pluton. It was originally mapped by Kynaston who traced it southwards to the angle of Loch Etive in a great arc, 10 miles long, corresponding roughly with the margin of the pluton (Fig. 18). It seems probable that it originated as a partial ring-fault, closely associated with the intrusion of the Etive Complex. H. B. M., E. B. B.

MECHANICS OF INTRUSION

The northern lobe of the Cruachan " Granite " seems to have invaded the Glen Coe Cauldron very shortly after subsidence *en bloc* had ceased, since it merges with the Fault-Intrusion at the east side of the Cauldron (p. 165), although it definitely cuts across the same intrusion at the west side, near Dalness.

Erosion has exposed the domed roof of this northern lobe, and shown that it consists of untilted lavas. Accordingly, it appears probable that the roof has not been bent up, but that the floor has sunk down in order to make room for the invading magma as the plutonic infilling of a subterranean cauldron (Fig. 30).

The southern lobe of the Cruachan " Granite " is naturally interpreted in like fashion. Kynaston has shown that it has a steep, smooth, eastern and southern edge which may readily be interpreted as the approximate margin of a subterranean cauldron. The western and north-western boundary is locally more complex in Sheet 45, and is margined by a fringe of " granitic " tongues ; but these may be compared with the more irregular parts of the Fault-Intrusion of Glen Coe. Moreover the close marginal association with the Meall Odhar partial ring-dyke and with the Allt Buidhe partial ring-fault emphasises the probability of a subterranean cauldron interpretation. The Allt Buidhe Fault is presumably a concentric flanking dislocation tending to enlarge the scope of the Cruachan subterranean cauldron by downthrow towards its centre.

When we wrote our 1909 account we also pointed to strong supporting evidence supplied by Kynaston's mapping and description of partial ring-structures at Beinn a' Bhuiridh at the south-east corner of the Cruachan Pluton (Fig. 18). The district lies wholly in Sheet 45 (Geol.) and is therefore not suitable for treatment in the present memoir. Readers are referred to Anderson's relatively recent paper, full of new information based on close field study (1937a, pp. 517-527). His corrections and amplifications have greatly strengthened in principle the inferences we had based upon previously available information.

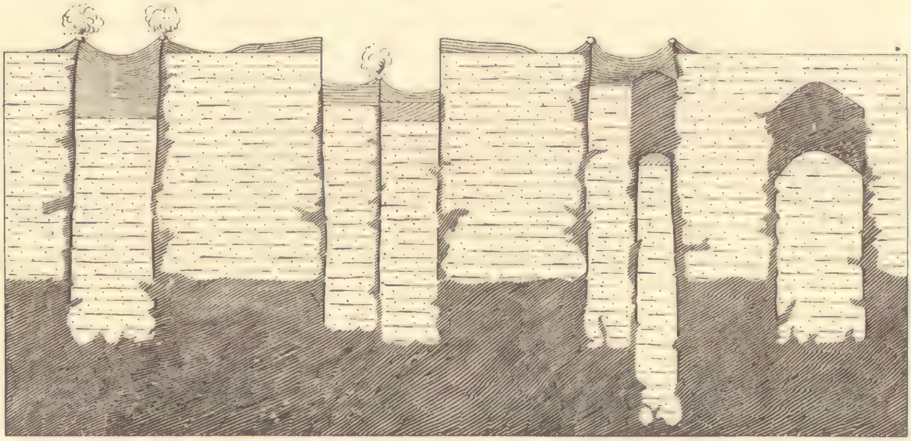


FIG. 30. Diagram of subaerial and subterranean cauldron-subsidences accompanied by volcanic and plutonic accumulations of igneous rocks

The Meall Odhar Granite of the type outcrop is a typical example of a ring-dyke. Like most of its kind it is partial in the sense that it is merely arcuate in plan and does not complete a closed curve. It is quite uncertain whether it opened up a single fissure, or occupied a space between two parallel fissures left vacant through contemporaneous foundering of an intervening strip of country-rock.

The similar granite of Stob Gaibhre, continuing south into Sheet 45, has been interpreted by Anderson as a gently inclined sheet, probably in large measure fed by the Meall Odhar ring-dyke. According to this reading it represents an early stage in the filling of a subterranean cauldron, where subsidence of the floor made of Cruachan " Granite " was soon brought to a halt.

That the Starav Granite likewise marks the site of a subterranean cauldron is rendered probable from the verticality of its margins. The core of Cruachan " Granite " which it replaces must either have gone up or down ; that the movement was downwards seems likely from the analogy of the Glen Coe subsidence lying at so short a distance to the north.

The foliation of some of the dykes in the neighbourhood of the Starav Granite may be ascribed to the movements which accompanied the introduction of the latter. Other mechanical aspects of the Etive Dyke-Swarm will be considered in chapter xvi. E. B. B.

CHAPTER XIV

ROCKS OF LOWER OLD RED SANDSTONE AGE

BEN NEVIS

INTRODUCTION

IN the present chapter the term " granite " between inverted commas will be employed, once again, in the popular sense to include both granite and quartz-diorite (also trondhjemite), especially in relation to the two big units shown as Outer Granite and Inner Granite in Fig. 31 (see also 1, Fig. 18). These two titles are convenient in describing field relations, and escape petrographical error if we enclose Granite in each case between inverted commas. The major features of the Ben Nevis story were discovered by Maufe (1910). His field work, however, consisted to a considerable extent in revision of previous incomplete mapping ; and he had no time to subdivide the Outer " Granite " beyond recognising in it a prevalent pink porphyritic type (4 of Fig. 31) merging rapidly outwards into a generally grey non-porphyritic margin (1-3 of Fig. 31). Since then J. G. C. Anderson has added much of interest in regard to the Outer " Granite " by subdividing its non-porphyritic margin (1935), and his results are incorporated in Fig. 31 and in the text which follows with due acknowledgment. The present writer had the opportunity of checking these results in the field under Anderson's guidance before the 1935 account appeared, and he then accepted them as essentially correct. In recent years, however, J. E. Wright has completed the Geological Survey mapping of the part of Sheet 62 (north of Sheet 53, both Geol.), into which the Ben Nevis Complex extends, and has reached an intermediate position. He agrees that Anderson is justified in recognising a sequence of intrusion in Maufe's non-porphyritic margin, and that in Allt na Caillich what Anderson refers to as Subzone 1 of Fig. 31 is pierced by veins referable to Subzone 3 ; but elsewhere he considers that there is too much variation and too much mingling of type to allow of confidence in the merging junctions drawn by Anderson to separate Subzone 1 from 2, and 2 from 3. Apart from this, Maufe, Anderson and Wright, all agree that the outer boundary of Subzone 4 can be traced with approximate accuracy, though usually of merging type (wherever it makes contact with Subzone 3) ; and Wright confirms Anderson's claim that this merging type of junction gives place to an abrupt junction on the two sides of Allt Daim (where Subzone 4, according to Anderson, makes contact with Subzone 1). All told, the differences between Anderson and Wright are not crucial, but they should be borne in mind in reading the following pages. Also all the new work fits so easily into Maufe's that it has been thought proper to retain the latter's initials at the end of this important chapter. The later contributions are self-evident interpolations. It may be added that exposures have deteriorated somewhat since Maufe and Anderson's days owing to afforestation and to underground diversion of the waters of Allt a' Mhuilinn and of its neighbour on the south. E. B. B.

The Ben Nevis massif is geologically divisible into three well-defined concentric zones (Fig. 31), which, reckoned from without inwards, are as follows :

1. A discontinuous, complex, outer ring, known as the Outer " Granite," steeply bounded externally against contact-altered schists. This Outer " Granite " has three successively younger

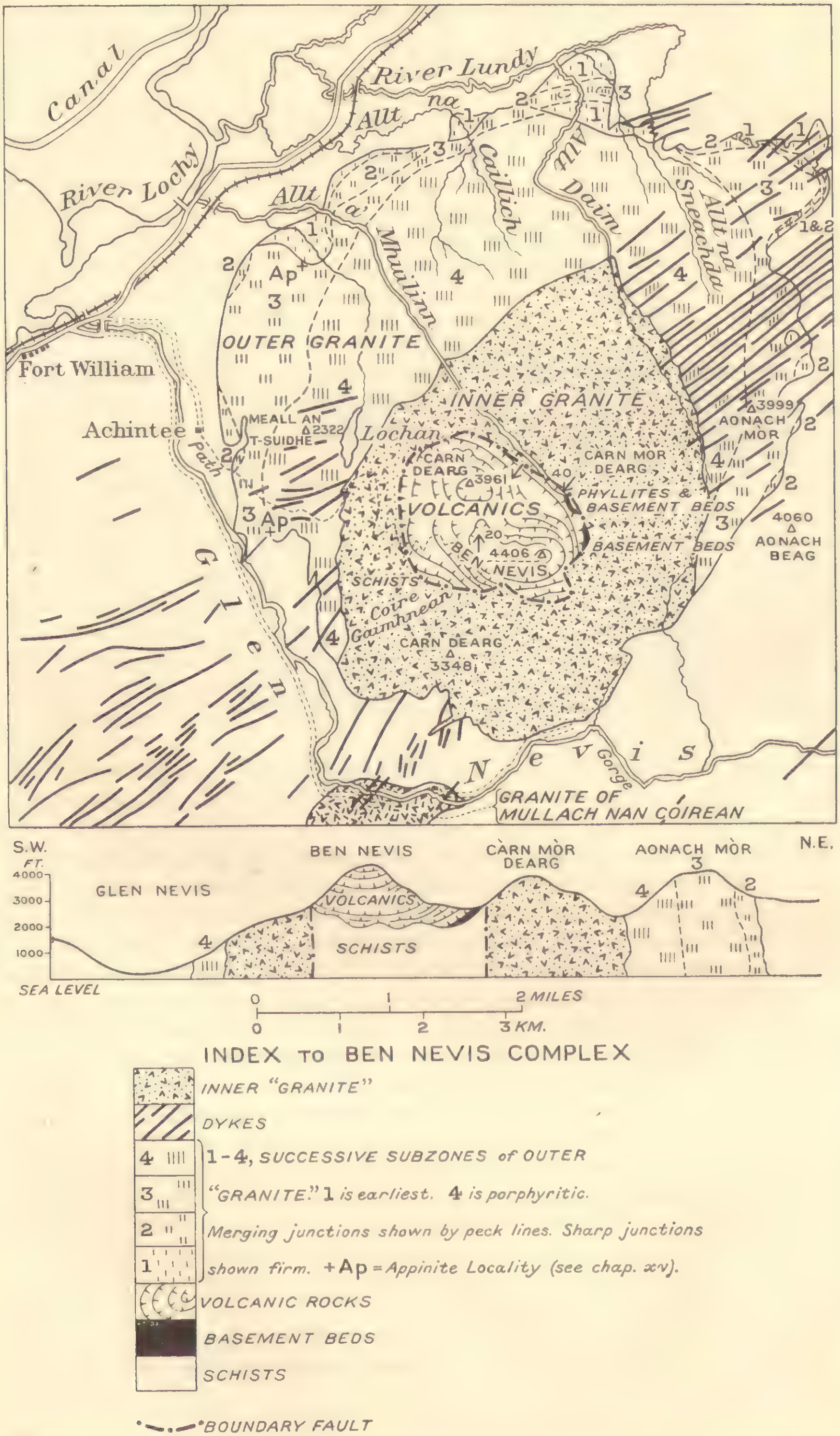


FIG. 31. Map and section of Ben Nevis

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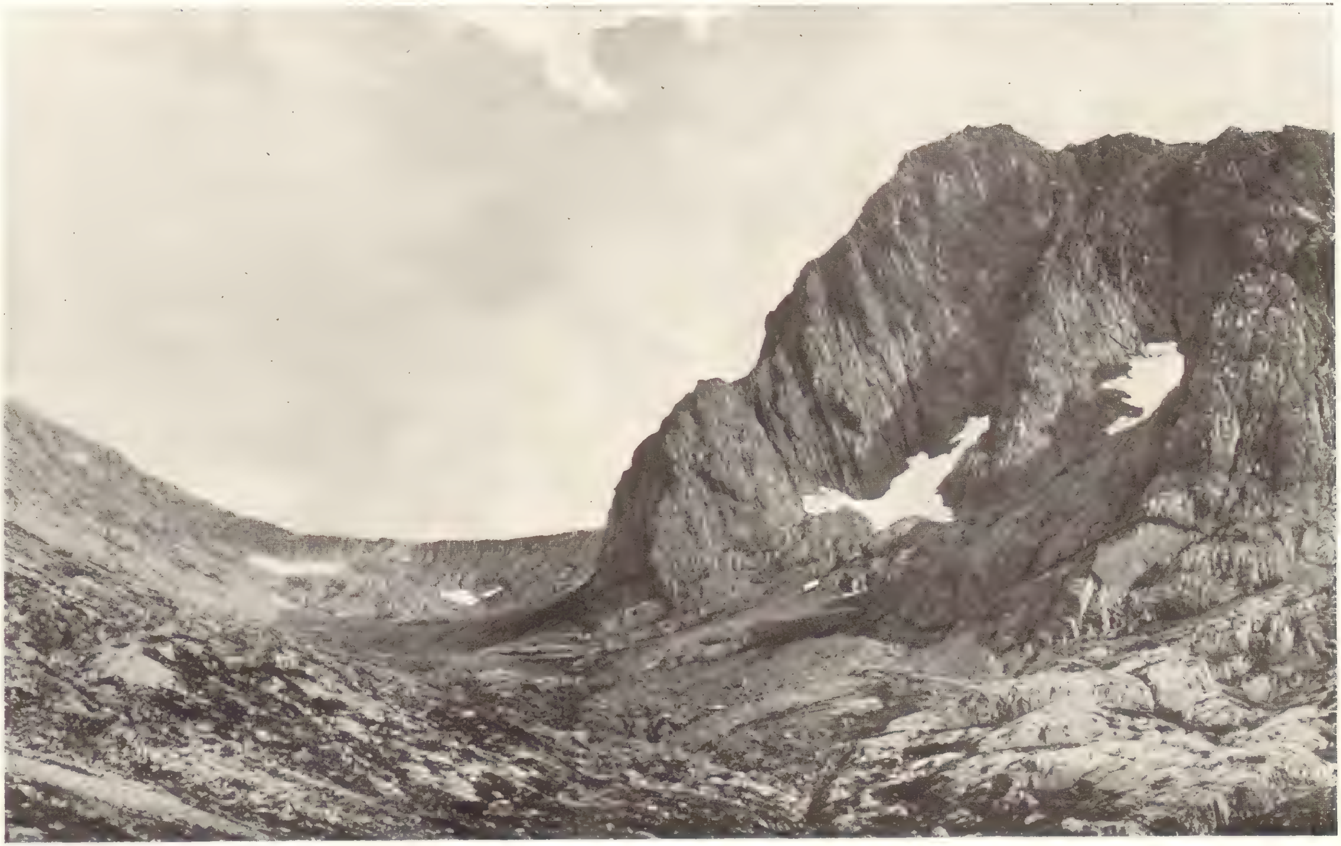

Allt a' Mhuilinn : Ben Nevis Volcanics on right, and Inner "Granite" on left, meeting in stream non-porphyritic Subzones, numbered 1-3 in Fig. 31 ; all three are as a rule quartz-diorite and carry augite. Then follows a still younger, porphyritic Subzone 4 which is a medium-grained pink granite with large phenocrysts of perthitic orthoclase.

2. A continuous inner ring, known as the Inner " Granite," with steep intrusive exterior and interior margins. This is of later date than the Outer " Granite ". Rather strangely, though more acid and poorer in ferro-magnesian minerals than the latter, it is richer in plagioclase, and much of it is now classed as trondhjemite. It is further distinguished by its finer and more even texture. It does not chill at its outer margin against Zone 1, but along its interior margin against Zone 3 it rapidly passes into rhyolite or andesite with vertical, streaky flow-structure. Recent re-examination has shown that this rhyolite is, in some cases at least, separated from the rocks of Zone 3 by a thin layer of flinty crush-rock (p. 162).

3. A central core, consisting of some 2000 ft of volcanic rocks, and an unknown thickness of underlying schists ; the volcanic rocks are hornblende-andesite lavas, with a fair proportion of agglomerate ; a few thin bands of associated sediment are also found, and the whole mass is disposed in a basin with steeply tilted margins. At two localities along the edge of the basin underlying schists are exposed to view, in one case forming a strip 200 yards long. They are phyllites, presumably belonging to the Leven Schists though their regional metamorphism is of much lower grade than that of the Leven Schists outside the igneous complex (p. 72).

A glance at Fig. 18, p. 129, shows that the Ben Nevis " Granite" has a retinue of dykes comparable with that of the Etive Complex. These dykes are porphyrites, lamprophyres, and allied types. Anderson has found a small group in Sheet 62 (Geol.) to the north of Sheet 53 to be earlier than the earliest Subzone (1) of the Outer " Granite " (1935b, pp. 248, 259, 260) ; but the great majority cut and chill against the latest Subzone (4) of this intrusion. Here most of them are in turn cut across by the Inner " Granite," though a very few penetrate this latter for a short distance. Thus, as in the case of the Etive Complex, the main dyke phase intervened between the intrusion of the two most important members of a " granite " pluton. We shall return to the Ben Nevis Dyke-Swarm in chapter xvi.

The tourist path leading from Achintee to the top of Ben Nevis affords an opportunity of verifying many of the foregoing statements. In ascending it one meets with banded green and white calc-silicate-hornfels before reaching grey non-porphyritic quartz-diorite representing Subzone 3 of the Outer " Granite ". Subzones 1 and 2 are missing here. Subzone 3 is 400 yards wide, and is cut by a couple of lamprophyric dykes. Beyond, for half a mile, the path traverses pink porphyritic granite, Subzone 4 of the Outer " Granite". This is traversed by many lamprophyric and porphyritic dykes, and also, near the bridges, by a quite distinct basaltic dyke, shown on Sheet 53, which has a general W.N.W. trend and is probably of Tertiary age. Beyond this the path, in its zig-zag course approaching Lochan Meall an t-Suidhe, thrice crosses the junction of the Outer and the Inner " Granites ". The difference of character can easily be recognised. The belt of Inner " Granite " when finally entered upon is found to be about a third of a mile wide, and is fairly well exposed in its more easterly portion. The last 1500 feet of the ascent are accomplished over frost-riven rubble of andesite and agglomerate. On the plateau below the summit, at about the 4000-foot level, a mass of agglomerate is exposed, containing abundant fragments of quartzite and phyllite.

From the number of blocks showing a brecciated structure on their weathered surfaces it might be thought that agglomerates constituted a large part of the volcanic pile. A closer examination reveals the fact that many of the apparent agglomerates are andesites, affected by flow-brecciation. These flow-breccias are particularly common in the upper portions of lavas. They may be conveniently studied in the small crags lying to the right of the path on reaching the summit plateau, and also around the cairn on that Càrn Dearg which lies north-west of the summit.

A more detailed account of the various geological units of the hill will now be given in reverse order.

VOLCANIC PILE

It is perhaps possible to separate two varieties among the hornblende-andesite lavas, one with abundant biotite, in addition to hornblende, the other with pseudomorphs, which probably represent a rhombic pyroxene. For the rest they exhibit only those small variations in composition and texture, which enable one to separate flow from flow but are otherwise of no particular interest.

The unstratified masses of agglomerate, which frequently intervene between the lavas, consist of angular blocks of hornblende-andesite of all sizes up to 4 feet in length. Mixed with these are blocks of red porphyritic felsite and occasional pebbles of quartzite and lumps of phyllite. It is often a matter of great difficulty to separate these compacted agglomerates from the lavas that show brecciform structure, and include xenoliths. Very fine exposures of agglomerate are afforded in the glaciated crags towards the head of Allt a' Mhuilinn.

The finer-grained parts of the agglomerate may show a certain amount of stratification, and pass gradually into the coarse-grained sediments associated with them. No tuffs with typical ash-structure have been discovered on Ben Nevis. Such rocks are indeed very rare in the related volcanic series of Lorne and Glen Coe.

The sedimentary rocks accompanying the extrusive series include green sandy shales, dark shales with slightly calcareous bands, and a conglomerate composed chiefly of quartzite pebbles. These rocks, which are present in insignificant proportions, closely resemble the sediments intercalated in the volcanic series of Glen Coe, though on Ben Nevis no fossils have as yet been obtained.

It was thought by some early observers that the volcanic pile reposes upon the surrounding " granite ". As a matter of fact the Inner " Granite " is bounded by a vertical chilled margin against the volcanic group—a relation especially well seen in the ridge at the head of Allt a' Mhuilinn, south-east of the summit. The junction is on the whole smooth, although breached here and there by an occasional tongue emanating from the " granite ". The lavas undergo changes through contact-metamorphism similar to those exhibited by andesites in other districts, with notable development of new biotite and hornblende, both in the groundmass and in the phenocrysts. The disposition of these altered rocks is quite in accord with what one might expect from the vertical course of the " granite " margin. The altered rocks form a rim round the volcanic massif, and extend up to the level of the summit, some hundreds of feet above the highest point now reached by the " granite ". Towards the centre of the massif the alteration dies away, irrespective of level.

We have already anticipated the question : On what foundation does the volcanic series rest, if not upon " granite " ? It is seen at two places resting unconformably upon the Highland schists in just the same manner as do the extrusive rocks of Lorne and Glen Coe. The larger and clearer exposure illustrating this relation is situated in Allt a' Mhuilinn, a short distance below the foot of the huge precipice north-east of the summit (Pl. X). Here contorted phyllites crop out beside the stream for a distance of 200 yards. Resting against them in unconformable relation is a basement conglomerate, largely made up of quartzite pebbles, and 8 feet in thickness. Following it come about 40 feet of indurated black shales with slightly calcareous layers, and then the lowest lava, a typical hornblende-andesite. Agglomerates and lavas succeed one another up to the summit, with a total thickness of probably not less than 2000 feet, and uninterrupted save for a couple of bands of dark shale. One of these bands has been followed for a short distance in the crags north of the two little lochans close together on the corrie floor, half a mile north-west of the summit.

The basement beds are traceable at intervals for more than half a mile along the eastern side of the central massif, and are then cut out in both directions by the bounding wall of " granite ". It is important to note that along the whole line the beds are dipping steeply inwards towards the centre of the volcanic mass. In one section, indeed, there appears to be a slight inversion. In places, too, the shales are contorted, the sharp folds being frequently fractured, and their limbs displaced. In Coire Gaimhnean, on the south-western side of the hill, where phyllites are once more exposed for a short distance between the " granite " and the lavas, the dip of the latter is again inclined inwards at a high angle. Passing from the edge towards the centre of the mass the dip diminishes, sometimes very rapidly, until on the summit ridge the beds are rolling at low angles. Evidently the volcanic massif of Ben Nevis has a basin structure and, surrounded as it is by a " granite " with vertical chilled margins (Fig. 31), it presents a close analogy with that of Glen Coe.

INNER " GRANITE "

The edge, which the Inner " Granite " of Ben Nevis presents to the central volcanic massif, has already been described as " chilled ". The result is a marginal zone of fine-grained rhyolite, with small, scattered phenocrysts of felspar and biotite, and with a strong, streaky flow-structure parallel to the vertical junction, along which a seam of flinty crush-rock is developed in (S 14044-5). This flinty crush-rock erodes the rhyolite as has been described in detail at Glen Coe (p. 162). The flow-structure of the rhyolite is even more apparent than that of the neighbouring andesite lavas. The external margin of the same " granite " is not marked by any such evidence of chilling, though it frequently assumes a grey colour in place of the normal pink colour.

The separation of the Inner and Outer " Granites " is perfectly definite. In Allt Daim an instructive section of the junction is exposed, in which the Inner " Granite " cuts right across an elongated " basic secretion " in the Outer, so that there can be no doubt that the Inner is the later of the two.

That the interval of time which separated the intrusion of the Inner " Granite " from that of the Outer was considerable is shown by the fact that the main phase of dyke injection intervened. The Outer " Granite " is freely cut by porphyritic and lamprophyric dykes which show no sign of falling off in numbers as one proceeds inwards into the " granitic " complex, until, suddenly, on reaching the Inner " Granite," scarcely a dyke is to be found. As a matter of fact only three such dykes have been detected in the Inner Granite—all of them in or close to Allt Daim.

Strong as this evidence is, it is not by itself quite conclusive : the three dykes found within the Inner " Granite " all occur close to the margin so that it looks as though the Inner " Granite " may have presented special difficulties to dyke intrusion. Can impenetrability alone account for the absence from the Inner " Granite " of the great swarm of dykes which intersect the Outer ? Fortunately this doubt can be silenced, for in five clear instances the Inner " Granite " is seen cutting right across dykes which traverse the Outer ; and in a great number of cases, where bare junctions are not exposed, dykes can be traced so close to the margin that the only feasible interpretation is that they are truncated by it. The five crucial examples are located as follows :

Two in gullies traversing the crags above Allt Daim, 1100 yards S.S.E. of the point at which the junction of the Inner "Granite" crosses the stream (S 14047 dyke cutting Outer "Granite" ; S 14048 same dyke cut by Inner " Granite ").

Another, 400 yards farther S.S.E. along the same line of crags (S 14048a dyke).

Two in Allt Coire Gaimhnean, the stream at the head of which the more southerly outcrop of the schists underlying the lavas of Ben Nevis is exposed (S 14049 dyke undoubtedly cut by Inner " Granite," S 14050, although the junction is hidden).

To this we may add that many of the dykes which cut the Outer " Granite " show contact-alteration under the microscope.

The margin between the Inner and Outer " Granites " is inclined very steeply outwards.

OUTER " GRANITE "

Anderson (1935b) has described and illustrated by appropriate maps the distribution and behaviour of the four Subzones of the Outer " Granite ". Here we need only briefly summarise his results. The three outer non-porphyritic Subzones, 1-3 of Fig. 31, are generally in the form of rather basic grey quartz-diorite with augite and, in 1 and 2, hypersthene ; but in their high eastern outcrops they become more acid and sometimes definitely pink and granitic. The main distinguishing feature in these three Subzones is textural. Subzone 1 is fine, 2 medium, and 3 coarse-grained. The average specific gravity in any one locality increases in the same direction from 1-3, to drop again materially in the porphyritic Subzone 4 (Anderson 1935b, p. 258). The coarse non-porphyritic Subzone 3 becomes pink and acid wherever it approaches Subzone 4, with which it always makes a merging contact. Subzone 4 is throughout a porphyritic granite with large phenocrysts of perthitic orthoclase.

Subzone 4 is continuous except for 3½ miles round the south-east end of the Inner " Granite " which here comes directly against external schists.

Subzone 3 is absent for an additional mile in the south-west, south of where it reaches the River Nevis. This is particularly interesting, for the failure of the subzone corresponds with a marked contraction of the Outer " Granite " outcrop. Subzone 3 also fails in the north for about a mile on the two sides of Allt Daim.

Subzones 2 and 1 are much less continuous, but they are present in many places, almost always external to Subzone 3 ; and, if both occur together, as is usual, Subzone 1 is almost always external to Subzone 2. The only important exception is in the northernmost protrusion of the pluton where an outcrop of Subzone 1 is, according to Anderson, bisected by an east-west band of Subzone 2 with central patches of Subzone 3.

Again according to Anderson, the full succession of subzones is seen in Allt a' Mhuilinn, with Subzones 1 and 2 occupying the stream bed, for about 50 yards each, Subzone 3 for a quarter of a mile, and Subzone 4 for more than a mile. Here, as everywhere else where the subzones succeed one another in the numbered order, 1 in contact with 2, 2 with 3, 3 with 4, the junctions are of merging type. On the other hand, where contacts between 1 and 3 and between 1 and 4 occur they are abrupt with associated evidence showing that 1 is earlier than both 3 and 4. Combining the two types of evidence we think Anderson is justified in believing that the Subzones 1, 2, 3, 4 followed one another in the order stated, and sufficiently quickly to anticipate in each case complete consolidation of the immediate predecessor ; and also that Subzone 1 had consolidated sufficiently to be veined and to yield xenoliths before it was followed by Subzones 3 and 4. Contacts between Subzones 2 and 4 have not been found.

In Fig. 31 merging contacts are shown by pecklines and sharp intrusive contacts by firm lines. The best exposures of Subzone 1 veined by and included in Subzone 3 are afforded in Allt na Caillich, and along crags west of the stream that drains the lochan east of Meall an t-Suidhe (Anderson 1935b, pp. 235, 237). A well exposed contact of Subzones 1 and 4 occurs in Allt Daim, but one can say little more of it than that the junction is sharp. On the other hand, in Allt an t-Sneachda, a little further east, Subzone 1 is cut by numerous granite and aplite veins, and Subzone 4 is full of xenoliths of Subzone 1. The actual contact is seen at a minor hydro-electric dam. Subzone 4 here retains its porphyritic character right up to the margin, though its phenocrysts do not enter into veins. Microscopic evidence confirms that it is the later of the two intrusions (Anderson 1935b, pp. 238, 254).

The steepness of the margin of the Outer " Granite " as a whole against the schists is visible in many sections around the edge of the complex. On a large scale it is patent from an examination of a contoured map showing the " granite " boundary.

GENERAL CONCLUSIONS

It is obvious, from the foregoing descriptions, that the structure of Ben Nevis admits of an interpretation similar to that applied, in the two preceding chapters, to the Glen Coe and Etive igneous centres.

The Outer " Granite " with its steep walls may be conceived as filling the void created by the gravitational sinking of a subterranean block into underlying magma (Fig. 30, p. 176). Then followed a long period during which the uprisen magma, at the level now exposed by erosion, consolidated and cooled. Anderson agrees that this mechanism is probable, and thinks that the subsiding central block had a top that was convex upwards, so that as it descended in a succession of steps it admitted relays of magma responsible for Subzones 1-4 (1935b, p. 264).

The main phase of dyke injection ensued (p. 202), and after it further subsidence, which, confined to the central area, admitted in complementary fashion the uprise of the Inner " Granite ".

Then a subaerial cauldron-subsidence developed, for the roof of the subterranean cauldron gave way, and a block of schists, with its burden of lavas, subsided into still liquid Inner " Granite ". The motion developed a streaky flow-structure in the magma, which itself became chilled against the cool descending mass. The latter, during its subsidence, buckled into its basin shape by reason of the friction on its walls ; and its cracked margin, on coming in contact with the magma, was penetrated to a slight extent by veins of granite. The sinking block in its descent must have dropped over 1500 feet. We are thus led to the conclusion that the lavas of Ben Nevis, in spite of their great altitude, owe their preservation, like those of Glen Coe, to subsidence. Erosion has cut relatively deeper at Ben Nevis than at Glen Coe, and has cleared away the fringe of fault-intrusion, which, analogy leads us to expect, rose from the reservoir of liquid Inner " Granite " more or less completely to surround the sinking mass at higher levels.

The local history seems to have closed with the injection of a few more dykes which pierce the margin of the Inner " Granite ".

A point which is not at all clear, is the relative age of the volcanic series and the Outer " Granite ". By analogy with other areas we may suppose that the volcanic rocks were extruded first. If this were so, it is perhaps remarkable that not a single dyke has been found cutting the volcanic rocks. At the same time the schists lying beneath the latter are equally free from dykes, though their outcrop runs at right angles to the trend of the dykes, and is sufficiently long to have included several of them if spaced at regular intervals. We can surmise either that the volcanic mass, in its original position, was above the level at which dykes were injected from the subterranean source, or perhaps that it was sheltered by some such mechanism as is discussed later on p. 201.

The interpretation given above of the development of the Ben Nevis Pluton is hypothetical except in regard to the unequivocal subsidence of the central cylinder of schist and lava. There is indeed a suggestion that outward magmatic push may have been a co-operating factor in making room for the pluton. The Glen Nevis outcrop of Ballachulish Limestone is cut out for a short space by the " granite " margin, but it soon reappears in Sheet 62 (*cf.* Fig. 17 and Bailey 1934a, pl. 15) well to the north-west of the position in which it might be expected. Traced north-eastwards away from the " granite " it swings back into its normal course. The deflection is undoubtedly linked with the emplacement of the " granite," but it has not been found possible to decide whether it betokens :

(1) a downward sag of the surrounding schists connected with subsidence of a central block,
(2) an outward magmatic push, or possibly
(3) a combination of these two causes.

Quite another point is made by Anderson who points out that the coarse non-porphyritic Subzone 3 of the Outer " Granite " is seen through a vertical range of 3900 feet from where it is washed by the River Nevis on the west to where it forms the summit of Aonach Mòr in the east, " the greatest exposed vertical thickness of any igneous intrusion in the British Isles " (1935b, pp. 243, 264). " In the high Eastern Area," he says, " all the Marginal Types [Subzones 1-3] are more acid than the corresponding Types in the outcrops at lower levels elsewhere. This difference may be explained as due to gravitational differentiation, such as has been described from the Mull ring-dykes (Bailey 1924, pp. 320-330) ".

H. B. M.

CHAPTER XV

ROCKS OF LOWER OLD RED SANDSTONE AGE PLUTONS OTHER THAN THOSE OF GLEN COE, ETIVE AND BEN NEVIS

ULTRA-ACID, ACID AND INTERMEDIATE

Mullach nan Coirean and Meall A' Chaoruinn Granites.—Let us start south-east of Loch Linnhe. The above-named two neighbouring bosses (2, Fig. 18, p. 129 ; Fig. 32) just south of Ben Nevis, were mapped by Grant Wilson. Together they measure four miles by two ; and both consist of a very pink or red medium-grained binary granite, much redder and with less ferromagnesian elements than the neighbouring Inner " Granite " (trondhjemite) of the Ben. They are, on the other hand, very similar to the Meall Odhar Granite of the Etive Complex (p. 171). The Mullach nan Coirean Granite is cut by a number of north-east dykes belonging to the Ben Nevis Swarm, so that it is earlier than the Inner " Granite " of Ben Nevis.

The resemblance of the Mullach nan Coirean and Meall a' Chaoruinn granites to one another is so close that it is probable that they are essentially one intrusion, and that the narrow strip of baked schist, forming the summit ridge between the two outcrops, may be regarded as part of the roof of a mass united below. This view is further favoured by the relation which seems to connect the sinuosities of the boundary of the Mullach nan Coirean Granite with the hill and valley system. It is probable, in fact, that we are dealing with a granite intrusion which has not yet been deeply bared by erosion. A similar example is afforded, it will be remembered, by the northern lobe of the Cruachan " Granite " where it penetrates the Cauldron-Subsidence of Glen Coe. E. B. B.

Moor of Rannoch " Granite ".—The Moor of Rannoch " Granite " (7, Fig. 18) is very conspicuous as the foundation of an extensive area of low-lying ground east of Sheet 53, and as such it early attracted attention. It enters Sheet 53 (Fig. 32) for only a short distance between Blackwater Reservoir and Càm Ghleann. Much the greater part of its outcrop, measuring about 16 miles by 12, lies in Sheet 54 (Geol.), so that readers are referred to the corresponding memoir by Hinxman and others for a full description (1923, chap. v). Fig. 18 of the present account brings out very clearly the geographical position of the Moor of Rannoch " Granite " in relation to the intrusive complexes of Glen Coe and Etive, numbered 6 and 8, and the lavas of Lorne, lying to the south-west. The Loch Laidon north-east fault is a sinistral wrench or tear-fault, which, though apparently earlier than the Lorne lavas, has strongly affected the Rannoch Pluton. The parts of this intrusion which lie north-west of the fault, including a detached outcrop west of Loch Tulla, have been shifted some 4½ miles to the left as compared with the rest lying to the south-east (Read *in* Hinxman and others 1923, p. 63).

The main type represented in the Moor of Rannoch Pluton is a non-porphyritic slightly foliated pale grey hornblendic rock which is distinctly dioritic in appearance, save that it has large blebs of quartz standing out as knots on the weathered surface. These blebs are elongated along the foliation, as also are numerous lenticular dark inclusions.

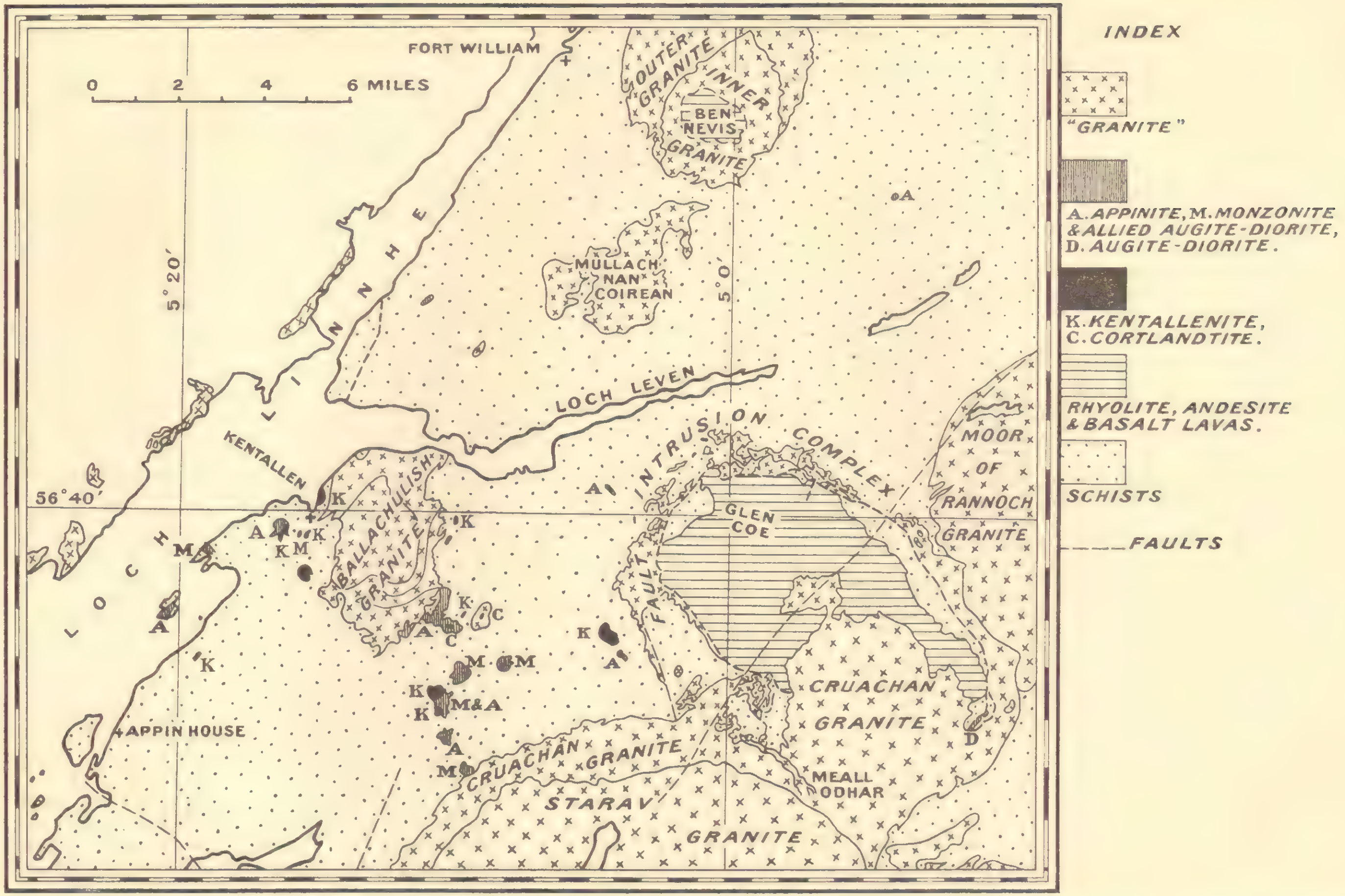

Fig. 32. Map of plutonic and volcanic rocks of Sheet 53 referred to the Lower Old Red Sandstone Period

Like the Starav Granite, it presents, in the district under consideration, a marginal porphyritic facies with which the interior non-porphyritic facies makes a merging contact. The marginal development is about half a mile wide, and, even apart from phenocrysts, differs from the interior in being pink, often free from hornblende and much less foliated—presumably it stiffened before the interior mass, full of crystals, had come to rest ; but it still shows the characteristic blebs of quartz. Its porphyritic character is not very striking, and is due to the presence of fairly large pink felspars. H. K., G. W. G.

In the terminology adopted in the present edition, the main rock is tonalitic quartz-diorite, ranging to trondhjemite, where its abundant quartz takes it into the acid category ; while the porphyritic facies is anything from trondhjemite, to biotite-granite approaching binary granite. To the east in Sheet 54 the porphyritic facies does not always occur at the edge of the pluton.

Although the porphyritic margin in Sheet 53 has been compared above with that of the Starav Granite, it should be noted that it is more acid than the non-porphyritic interior into which it merges, whereas at Starav the reverse is true. Still another arrangement, it will be remembered, holds in the Outer " Granite " of Ben Nevis, for there a more acid porphyritic interior merges outwards into a more basic non-porphyritic exterior, itself complex.

The margin of the Moor of Rannoch Boss in the neighbourhood of the Blackwater Reservoir crosses flat drift-laden country. It is well exposed, however, at Beinn a' Chrùlaiste where it is distinctly complex. To the south of this a narrow slice along the edge has been cut away by the Fault-Intrusion of Glen Coe. Under these circumstances it is not possible at present to express a firm opinion regarding three-dimensional shape. A strong suggestion, however, is afforded by scattered readings of the flow foliation. These were all taken in Sheet 54 (Geol.) though within a couple of miles of the western margin of the pluton ; and they show that the foliation in this neighbourhood is everywhere steep or vertical, and that it swings round from a north-westerly strike in latitude 56° 39′ to a north-easterly strike in latitude 56° 42′. The more northerly observations were taken by E. M. Anderson. H. K., E. B. B.

It has already been pointed out that the Fault-Intrusion of Glen Coe is later than the Moor of Rannoch " Granite " (p. 165) ; and, of course, all or almost all the Etive Complex is later still. In agreement with this, dykes of the Etive Swarm cut the Moor of Rannoch " Granite " absolutely freely (Fig. 18). Going back in time, one may recall how boulders with some particular features of marginal Moor of Rannoch " Granite " appear in a Càm Ghleann conglomerate belonging to the Glen Coe volcanic series (p. 147). All this suggests that the Moor of Rannoch " Granite " is one of the earliest igneous rocks of the district, though seemingly later than the lamprophyre sheets of chapter xvi. It may still, along with these latter, quite well belong to the Lower Old Red Sandstone suite, with which its position and lithology seem to connect it (p. 131). G. W. G.

Ballachulish " Granite ".—The Ballachulish " Granite " (5, Fig. 18 ; Fig. 32) also early attracted attention from geologists, which is not surprising since it furnishes a conspicuous exposure on the south shore of Loch Leven at Ballachulish Ferry. The whole mass measures five miles from north to south, and two from east to west. It was first carefully mapped by Grant Wilson, but without subdivision. Later, T. R. M. Lawrie has separated it into early grey quartz-diorite or tonalite, mostly marginal, and later pink granite, mostly central. His mapping, reproduced on Sheet 53 and Fig. 32, shows that the interior granite has two separate outcrops. In both it definitely cuts the quartz-diorite ; but it is impossible to say whether or no its two separate portions are strictly contemporaneous. One of them appears to be a central core, the other an incomplete ring-dyke.

References to Ballachulish granite in previous literature concern the grey quartz-diorite. This is a medium-grained rock with small spangles of biotite and less conspicuous hornblende; and unlike many tonalites it is devoid of foliation. A conspicuous feature is provided by an unusual number of xenoliths in various stages of alteration (chap. xviii), a character that recalls the Fault-Intrusions of Glen Coe. Many of these xenoliths correspond with the adjacent sedimentary schists, while others, Lawrie has found, may be matched in the abundant closely associated basic intrusions to be described later on in this chapter. Some of the basic inclusions are quite large, and a good example is exposed in the stream bed a mile up Gleann a' Chaolais. This evidence confirms, what is clear on the map, that the Ballachulish Quartz-Diorite has interrupted the distribution of the basic intrusions clustered about it. The quartz-diorite is itself cut by a few dykes, presumably belonging to the Ben Nevis Swarm.

The schists are not deflected by the presence of the Ballachulish Pluton along most of the exposed contact. On the western side, however, they are turned towards the north-west, just as they are along the north-west margin of the Ben Nevis Boss. As has been pointed out in connexion with Ben Nevis, there are two possible alternative explanations (p. 184). The schists may perhaps have been pushed *outwards* during the intrusions of the magma, or they may perhaps have been dragged *downwards* during development of a subterranean cauldron.

The presence of so many small xenoliths in the Ballachulish Quartz-Diorite suggests that there may have been much piecemeal stoping of the type advocated by Daly (1914), or else that explosion helped make the cavity now occupied by the pluton. In the latter case much country-rock may have been blown into the air, or poured out carried by xenolithic lavas.

In a roadside quarry at Rudh' a' Bhaid Bheithe, about a mile north-east of Kentallen pier, the Ballachulish Quartz-Diorite is separated from gritty Appin Quartzite by about 30 feet of quite unusual whitish " granite " cut by pegmatite veins. The " white granite " band is vertical, and F. Walker in an interesting paper treats it as a strictly localised marginal facies of the normal grey quartz-diorite (1924). Lawrie, however, has found that in most of its short course to the north-east the " white granite " is separated from the quartz-diorite by a strip of quartzite ; and he thinks that it is better interpreted as an early dyke, possibly a ring-dyke. Walker describes a merging junction between " white granite " and quartz-diorite, whereas Lawrie found a sharp contact—which suggests that slightly different exposures may have been available to the two observers. At any rate, there is complete agreement that at both its margins the " white granite " contains dark hornblende and biotite which, towards the interior, are gradually exchanged for almost colourless varieties, while concurrently iron sulphide becomes abundant—magnetic according to Lawrie (*cf.* pp. 38, 251). In keeping with these observations Walker points out that Analysis 27, p. 207, of the interior " white granite " shows a third of the iron combined with sulphur. Apart from this special feature the analysis has been matched by J. G. C. Anderson (1935b, p. 251) with one of the Inner " Granite " of Ben Nevis. This point will be taken up again in chapter xvii, where it will be claimed that the " white granite " is a fairly good example of trondhjemite.

Coastal Granites, Inversanda to Rudha na h-Earba.—Grant Wilson has mapped a multitude of red granite veins in the schists on the north-west side of Loch Linnhe. They characterise a coastal zone reaching south-west from the north border of Sheet 53 almost as far as Inverscaddle Bay.

South of this (3, Fig. 18), Grant Wilson has mapped a discontinuous series of elongated narrow granite bosses at intervals along the shore of the loch as far south-west as Rudha na h-Earba. The prevalent type is a bright red quartzo-felspathic granite like that of Mullach nan Coirean. On the western shore of Camas Shallachain there is much felspathisation and *lit par lit* injection of the schists, apparently in connexion with this suite of red granite intrusions. The phenomena recall those already described in relation to the Fault-Intrusion of Glen Coe.

What is shown at Rudha na h-Earba as granite overlain by a small outcrop of conglomerate (see Sheet 53 and Fig. 18) has been found by J. G. C. Anderson to be more properly described as felspathised Moine Schist with granite veins. The conglomerate is described in chapter xix.

Most of the granite outcrops along Loch Linnhe are considerably shattered owing to movement along the Great Glen Fault. To judge, however, from the alinement of those mentioned above, there seems no doubt that they are not altogether earlier than the movement which has taken place along this dislocation.

Strontian " Granite ".—A " granite " (4, Fig. 18), long known to Scottish geologists at various localities, has been named after the village of Strontian in Sheet 52 (Geol.). It enters Sheet 53 for a short distance at Gleann Feith 'n Amean, north of Glen Tarbert, and to a greater extent along the shore of Loch Linnhe. Here, between Rudha na h-Airde Uinnsinn and Cilmalieu it makes a ridge called Druim na Maodalaich.

The Strontian " Granite " as a whole is a major complex. To the south-east it is cut off by the Great Glen Fault (Fig. 18), which, running along Loch Linnhe, must bring it and associated Moine schists against the little-metamorphosed limestone that builds the islands of Lismore and Shuna. As exposed north-west of the Great Glen Fault it measures 17 miles by 7.

Much the greater part of the complex lies in Sheet 52, with a southerly extension into Sheet 44, and the whole has been described by MacGregor and Kennedy (1932). These authors recognise three main members, which in order of time, position and increasing acidity are as follows :

(1) Outer Member.—tonalite, a medium- to coarse-grained grey biotite-hornblende-quartz-diorite, probably as a rule intermediate, and with a prevalent flow-foliation.

(2) Mid Member.—porphyritic " granodiorite," grey, but distinguished from (1) by flesh-coloured phenocrysts of perthitic orthoclase. The rock probably ranges from intermediate to acid.

(3) Inner Member.—biotite-granite, finer in grain than (1) and (2), pink in colour and acid.

Of these three the tonalite (1) is typically exposed in Gleann Feith 'n Amean and, just outside the border of Sheet 53, in Glen Tarbert; while the porphyritic " granodiorite " (2) makes most of Druim na Maodalaich; and the granite (3) provides bands that cross the schists of Glen Galmadale and, further south, cut the " granodiorite " (2).

Marked deflection of country-rock is shown in Sheets 52 and 53 in the course followed by the quartzite of the Moine Series which is mapped (in Sheet 53) across Gleann Feith 'n Amean, Glen Tarbert and Creach Bheinn to reach almost to Cilmalieu. This deflection has already been referred to magmatic pressure of the Strontian Complex (p. 117).

A striking feature of the outer edge of the tonalite (1) in the Glen Tarbert neighbourhood, is its verticality. Another is the presence of a fringing zone characterised by innumerable small intrusions of a fine-grained pale-grey granite, too small to show on the map. In the same zone there is a multitude of little bosses of hornblendite and appinite, of earlier date than the tonalite, but obviously closely related thereto.

The Strontian Complex as a whole is cut by a few broad east-west dykes of salmon-pink felsite in addition to several later west-north-west Tertiary dolerites.

The lithological similarities shown by the rocks of the Strontian, Ben Nevis and Etive Complexes are so obvious that probably no one questions their being products of a single long period of igneous activity. At present they are tolerably close neighbours situated either side of the Great Glen Fault. If this latter is a wrench with 65 miles of horizontal displacement, the Strontian Complex may have formed at a much greater distance than now separates it from the other two (chap. xxi) ; but this would not introduce any serious doubt as to its essential contemporaneity with them.

Thus we are led to accept the Strontian Complex as of Lower Old Red Sandstone age, with always the possibility that it may be a little older. The felsite dykes which cut it cannot, on the basis of experience elsewhere in Scotland, belong to any later period, unless possibly the Tertiary. The question, therefore, arises : why do these dykes run east-west instead of north-east parallel to the dykes of the Ben Nevis and Etive Swarms ? No firm answer can be given. The difference of direction, as Richey has pointed out (1939, fig. 2, pp. 403, 410, 429), extends far beyond Sheet 53, and is in some way connected with the Great Glen Fault. It may, perhaps, be due to difference of age. Fig. 33 (p. 196) shows early felsite and andesite dykes in the Glen Coe region, which exhibit no tendency at all to adopt the direction later taken by the dykes of the same region forming the Etive Swarm.

SMALL PLUTONS OF APPINITE, BIOTITE-AUGITE-DIORITE, MONZONITE, KENTALLENITE, CORTLANDTITE

North-West of Loch Linnhe.—Let us exclude the Glen Scaddle " epidiorite," considered in chapter ix. This still leaves, north-west of Loch Linnhe, the many minute outcrops of appinite (S 10937) noted above as occurring in a restricted zone just outside the tonalite member of the Strontian " Granite " Complex, where this latter crosses Glen Tarbert. The geographical relationship is so definite (here and elsewhere in Sheet 52, Geol.) as to render it certain that the appinites concerned are pre-tonalite members of the Strontian Complex (MacGregor and Kennedy 1932, p. 107).

South-East of Loch Linnhe.—In the portion of Sheet 53 south-east of Loch Linnhe all the rock types mentioned in the title of this section are so often and so closely associated with one another and with small outcrops of " granite " as to leave no doubt of approximate contemporaneity. At the same time, if Sheet 53 stood by itself, there is no geographical connexion with a major " granite " pluton, which might not be ascribed to accident. Fortunately, however, we can turn back to Fig. 18, p. 129, which covers a much larger area ; and here it is manifest that the Ballachulish (5) and Garabal (9) centres have functioned as significant foci about which most of the characteristic little basic bosses of the South-West Highlands are gathered. A suggestion of consanguinity between the basic intrusions known at the time from Sheet 53 and the Ballachulish quartz-diorite was first advanced by Teall (1897) ; and afterwards the same general proposition was strongly argued by Hill and Kynaston (1900). Now that the subject has been fully examined the conclusion seems inescapable. The evidence furnished by the Garabal centre will be found in Dakyns and Teall (1892), Hill and Kynaston (Beinn Bhuidhe area, 1900, pp. 535-43 ; also Hill *in* Hill and others 1905, p. 94 ; Kynaston *in* Kynaston, Hill and others 1908, p. 95), J. G. C. Anderson (Arrochar area 1935a ; Glen Falloch area, 1937b) and Nockolds (1941). Independent confirmation can be derived from Anderson's demonstration that the Beinn a' Bhuiridh hornblende-mica-diorite is identical in composition with an Arrochar pyroxene-mica-diorite (Anals. V and D, 1937a, p. 518). The Beinn a' Bhuiridh diorite, as Fig. 18 shows, is indisputably part of the Etive Complex. Supported by this finding it is reasonable, though not conclusive, to regard the basic intrusions between Beinn a' Bhuiridh and Glen Orchy and Loch Tulla as also belonging to the Etive centre. Two minute kentallenite outcrops near Loch Avich seem non-committal, but they have been, with probability, referred to the Loch Melfort centre (Hill and Kynaston 1900, pp. 534, 546 ; Kynaston *in* Hill and others 1905, p. 98).

We shall now restrict attention to Sheet 53 and start with isolated occurrences in the north.

Two very small outcrops of appinite are indicated in the map of Ben Nevis, Fig. 31. They cannot with any certainty be claimed as more than casual associates. They might for instance be interpreted as contamination products. The more southerly (S 14046) constitutes a local marginal facies, only inches wide, of the porphyritic Subzone 4 of the Outer " Granite ". It is seen in the large stream round which the tourist track zigzags on its way to the summit. The more northerly was found by J. G. C. Anderson on a conspicuous crag 100 yards north by east of the hydro-electric surge-chamber (easily located on the ground). It merges into surrounding coarse quartz-diorite of Subzone 3.

Another tiny outcrop of appinite occurs, in isolation, a mile north-east of the summit of Binnein Beag (S 14082).

The Ballachulish group of little basic bosses, mostly mapped by Grant Wilson and reproduced in Fig. 32, illustrates very well :

(1) The tendency for close association of the various basic types with one another and with small " granitic " occurrences.

(2) Their somewhat earlier age than the main Ballachulish and Etive Plutons.

(3) The certainty that kentallenite and closely related biotite-augite-diorite have existed as rather potash-rich basaltic liquids charged with large phenocrysts of olivine and augite—this last point is revealed by the frequent occurrence of chilled basaltic facies full of big crystals of olivine and augite ; and it supports the commonly held opinion that gravity-concentration of early phenocrysts may have played an important part in the development of kentallenite.

Beginning in the west we find appinite in Eilean Balnagowan (S 7002).

Then on the mainland, a mile and a half to the south-east, a dyke of kentallenite (S 8830) is met with in the glen draining west from Beinn Sgluich.

Also on the mainland, but a mile and a half north-east of Eilean Balnagowan, Rudha Mòr supplies a shore section of biotite-augite-diorite (S 7055).

Inland, two miles further north-east, Ardsheal Hill, above Ardsheal House, has proved, on careful study by F. Walker, to be a veritable museum of types (1927). The summit-complex consists mainly of orthoclase-olivine-basalt passing into kentallenite, and of appinite passing into hornblendite. There is also a little granophyre—granophyric groundmass is a commonplace among appinites. Some of the summit appinite has green hornblende and may be intimately interbanded with kentallenite, at the same time presenting sharp junctions. On the other hand, towards the south, appinite with brown hornblende occurs, apparently penetrating into, and reacting with, kentallenite. Walker concludes that " there can be little doubt that both main types [appinite and kentallenite] originated from the same magma basin, and the change from a pyroxenic to a hornblendic facies may possibly be attributed to migration of aqueous and other fluxes produced, during crystallisation, in increasing concentration in the liquid portion of the magma." The only Geological Survey slice from the summit-complex is a biotite-augite-diorite (S 7054) with more hornblende than usual. To the east of the summit-complex Walker has mapped five very small outcrops, one of granophyre, three of biotite-augite-diorite and one of kentallenite ; while to the south he found a little patch of granodiorite (1927, fig. 2).

A mile further north-east, across Kentallen Bay, the type kentallenite (S 7053) is exposed in a fair-sized roadside quarry. The railway adjoins and cuts through the outcrop, while Kentallen railway station and pier lie a little to the north. The handsome black kentallenite, once worked as an ornamental stone, is pierced by a few white felspathic segregations, which may be thin and straight, or broad and patchy (S 15873-5). Some of these veins carry large gleaming biotites which clearly link them with the parent kentallenite—they are not offshoots of the neighbouring Ballachulish quartz-diorite pluton. Similar felspathic segregation has been noted by Kynaston in the Glen Orchy kentallenite (*in* Kynaston and Hill 1908, p. 94).

The kentallenite of Kentallen was first described and figured by Teall in his *British Petrography* (1888, pl. xvi ; 1), but without, at that early date, recognition that much of the felspar was orthoclase—as one might expect from the abundance of biotite. After it had been mapped by Grant Wilson for the Geological Survey in 1896, it was re-described by Teall, who pointed to its analogies with olivine-monzonite (1897, p. 22). In following pages of the report, in which this description occurs, reference is made to two similar outcrops mapped by Hill near Beinn Bhuidhe and Loch Avich in 1892 and 1896 respectively (Fig. 18)—but localities were confused in 1897 (*cf.* Hill and Kynaston 1900, p. 502). Since then several additional exposures of this exclusively South-West Highland type have been encountered, making about a score, including one in Colonsay west of Fig. 18.

Still west of the Ballachulish Pluton one of the biggest of these small outcrops of kentallenite has been mapped by Grant Wilson in Glen Duror. It is described as much decomposed.

Now let us cross the Ballachulish Pluton. On its north-east side, Grant Wilson and Lawrie have mapped quite a few minute basic bosses within a mile north of Sgòrr Dhearg. The largest lies half a mile north of the summit and is kentallenite with a little associated appinite. Another, 300 yards north of the summit, is biotite-augite-diorite.

Two miles to the south, we find an irregular belt of appinite (S 11364, 114434)- and appinitic diorite, which serves as an approximate south-east border to the quartz-diorite of the Ballachulish Pluton, occupying this position with a short break for almost two miles. It is sometimes in contact with the quartz-diorite, but is more often separated by a strip of Appin Quartzite or Leven Schist, much baked. Where the appinite belt projects eastwards it encloses a small outcrop of decomposed cortlandtite (S 11442).

North-east of the tip of the appinite extension just mentioned, and a mile west of the mapped footpath leading south from Ballachulish, a tiny isolated exposure consists of biotite-augite-diorite, to the north, and of kentallenite, to the south.

Beyond this, for a mile along Allt Eilidh there lies a minor " granitic " boss. A slice (S 11363) shows this to be trondhjemite, much like the Inner " Granite " of Ben Nevis. Grant Wilson noted abundant " pyrites," a feature recalling the " white granite " (trondhjemite) described west of the Ballachulish Pluton (p. 188). The Allt Eilidh trondhjemite is now flooded to give a fishpond, but Grant Wilson previously had found a small central outcrop of beautifully fresh cortlandtite (S 11441).

A mile to the south, Glen Creran affords important exposures of three bosses of biotite-augite-diorite. The most south-westerly, between two houses, Salachail and Barnamuc, (S 11362) is associated with two outcrops of kentallenite, which lie respectively at its north-western (S 11357-8, 11360-1, 11435, 11438, 11445) and southern (S 11439, 11440) extremities. Of the above (S 11358, 11435, 11438, 11440) are marginal kentallenitic types which show a strong contrast between large phenocrysts of olivine and augite and a fine-grained basaltic matrix. Grant Wilson collected (S 11358) half a mile north of Barnamuc as the fine-grained edge of the northern kentallenite against the biotite-augite-diorite. This suggests that the kentallenite here is the later of the two—but possibly the kentallenite chilled against schist which was subsequently displaced by diorite. A neighbouring specimen (S 11435), apparently collected in the bed of the River Creran, is described as from a dyke cutting kentallenite. Both the chilled edge of the dyke (kentallenitic basalt) and the country-rock (kentallenite) are well seen in the slice. Taking the little complex as a whole, Grant Wilson found that the biotite-augite-diorite, as well as the two associated kentallenites, chills against external schist. One slice (S 11359) shows that appinite is associated with the biotite-augite-diorite, but to what extent is not known. The specimen came from the Barnamuc tributary to the Creran, above a sheep-fold.

A quarter of a mile further up Glen Creran we find the middle member of the Creran trio, east of Salachail. A specimen has been analysed (S 14113) and is so rich in potash that the rock has been classed as monzonite—all the biotite-augite-diorites approach this type. Grant Wilson again records chilling at contact with the surrounding schist.

Another mile upstream, the most easterly of the Creran trio is met with downstream from Corbhainn south of Meall an Aodainn. It is a particularly handsome rock (S 11431), with conspicuous large green augite crystals scattered through a greyish white base. If more conveniently placed it would make a fine ornamental stone.

From the Creran trio we may now turn to a mile south-south-east of Barnamuc, where Sheet 53 and Fig. 32 show a small boss of appinite one mile north-east of Glenure House. This is a generalisation, for much of the outcrop consists of a decomposed " granitic " rock, perhaps originally tonalite (S 11432) ; but marginal specimens are appinite (S 11433-4).

A mile to the south-east again, in Glen Ure, Kynaston found still another dioritic outcrop, in contact this time with the Cruachan " Granite ". This proves to be baked biotite-augite-diorite (S 10125), and the occurrence has already been described as showing that the " granite " is later than the diorite (p. 170).

Northwards once more, half way between Glen Ure and Glen Coe, Maufe mapped unusually basic kentallenite north-east of Sgòr na h-Ulaidh (S 11573-4).

Then east of the same mountain, in the corrie of Gleann Chàrnan, Kynaston found ultrabasic appinite (S 8267), allied to hornblendite, cutting a coarse breccia made of schist. This breccia is shown on Sheet 53 as Old Red sediment, but reasons have already been given for interpreting it as explosion-breccia occupying a volcanic neck (p. 151).

Four miles to the north again, two small bosses of appinite (S 11036-7) occur beside the old Glen Coe road near Leacantuim (Fig. 10, p. 70). With them there is closely associated biotite " granite," much decomposed. There are also acid segregation veins consisting mainly of quartz and felspar, often in micrographic intergrowth. A few long needles of hornblende grow in from their sides (S 11906).

An augite-bearing diorite occurring along the inner branch of the Glen Coe Fault, at the south-east corner of the Cauldron-Subsidence is mapped as Early Fault-Intrusion in Fig. 29, p. 164. It is a hornblendic rock, with small augites (S 9133, 13406), and is not very like the biotite-augite-diorite of the little bosses listed above. On the other hand, it is well-nigh identical with the Beinn a' Bhuiridh diorite (S 7603-4, 8265-6, 9018) described by Kynaston at the south-east corner of the Etive Complex (*in* Kynaston, Hill and others 1908, p. 85) ; and this it will be remembered has been matched chemically with a small boss of biotite-augite-diorite from Arrochar (p. 191). E. B. B.

CHAPTER XVI

ROCKS OF LOWER OLD RED SANDSTONE AGE
DYKES AND SHEETS[1]

EARLY LAMPROPHYRE SHEETS

MANY more or less horizontal sheets of hornblende-vogesite and spessartite traverse the schists in that part of the district which lies east of Caolasnacon on Loch Leven. They yield very readily to erosion, and thus often give rise, indirectly, to scarps and waterfalls. Very good examples run along the hill slopes west of Allt Coire an Eòin, north-east of Ben Nevis, and others are well exposed in the River Leven. They weather in a rugged carious fashion on account of their richness in calcite. W. B. W., E. B. B.

The most southerly example known in Sheet 53 occurs at the base of the thin tremolitic hornfels, representing the Ballachulish Limestone, 1060 yards slightly east of south of Dalness. It is thrown by a small dislocation of the type connected with the Cauldron-Subsidence of Glen Coe. C. T. C.

The lamprophyre sheets are certainly of comparatively early date, for very numerous examples have been seen to be cut by the north-east dykes. They are probably earlier than even the Moor of Rannoch "Granite," since, though well developed in its vicinity, they are nowhere known to cut it. It is likely that they are of the same general age as the little appinite bosses of the last chapter, for petrographically they differ from the appinites only in their finer texture.

W. B. W., E. B. B.

In agreement with the view that these lamprophyre sheets are of earlier date than most of the igneous rocks of the district, it is interesting to note that a typical example exposed in a cutting in private ground, at the east end of the Aluminium Factory at Kinlochleven, shows a cross-cleavage. It cannot, however, be too clearly recognised that this is a local phenomenon and restricted, so far as is known, to this single example—unless the somewhat foliated lamprophyre described at the beginning of the next paragraph is a comparable case. E. B. B.

LAMPROPHYRES, UNCLASSED

On the river Leven, at the fall between the two main lochans a little down from the Blackwater Dam, a remarkable mass of lamprophyre occurs with distinctly foliated margin. At this point there is also a complex of porphyrite dykes which are chilled against the lamprophyre and against one another.

In the path to the north another lamprophyre is exposed with inclusions of quartz, quartzite, quartzose schist and granite. The granite is coarse and contains abundant very pink felspars. There is one large fragment of granite from which crystals have floated off at the margin into the lamprophyre magma. W. B. W.

Of other unclassed lamprophyre intrusions we may note the east-north-east dyke (S 11612) of hornblende-spessartite or vogesite mapped by Peach in the River Coe, south-west of Clachaig (p. 79). It is cut by an ordinary porphyrite dyke, and possibly belongs to the same suite of intrusions as the more or less horizontal sheets described in the previous section.

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[1] A fuller treatment in some respects has been given elsewhere (Clough, Maufe and Bailey 1909, p. 640).

Another example is a thin north-east lamprophyre dyke (S 11523) veined and baked by the Fault-Intrusion of Glen Coe. It is exposed in an important tributary, which enters Allt Gleann a' Chaolais from the east, but is not shown on the one-inch map. This dyke also may be closely related to the sheet series of intrusions. Nearby yet another lamprophyre dyke (S 11524) shows even more clearly contact-alteration by the Fault-Intrusion. E. B. B.

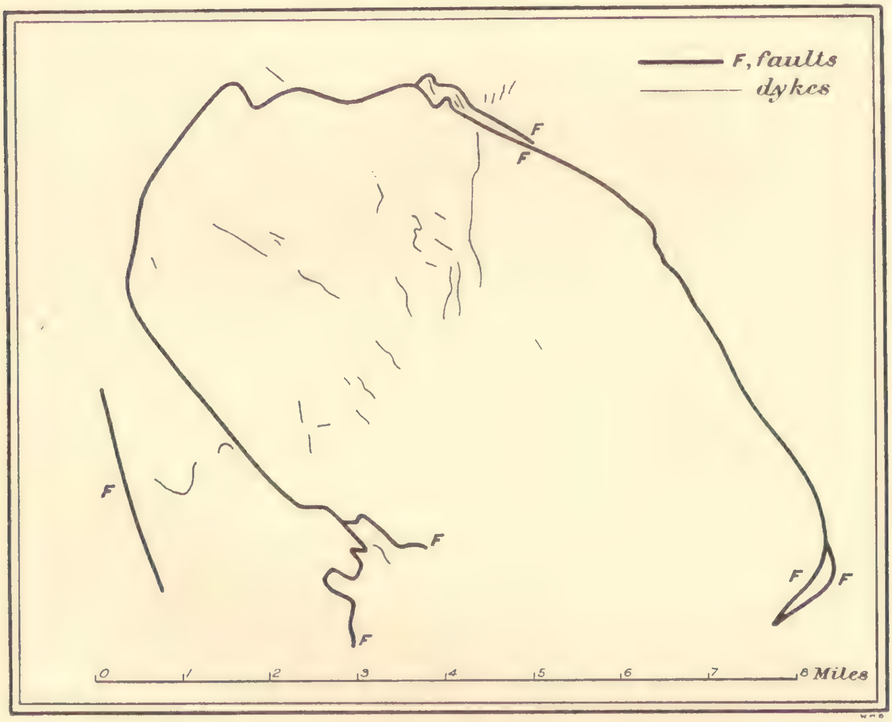


FIG. 33. Map of early felsite and andesite dykes of Glen Coe

On the north slopes of Sròn na Crèise a hornblendic lamprophyre cuts the quartzose schists a little beyond the edge of the lavas. It has the form of a small dyke running north-west (S 9738). H. K.

EARLY FELSITE AND ANDESITE INTRUSIONS OF GLEN COE

The horizontal lamprophyre sheets dealt with in the first section of this chapter are quite likely earlier than the Glen Coe lavas. The felsites and andesites now to be considered (Fig. 33) are probably, as a group, contemporaneous with the lavas ; they are early only in relation to the Fault-Intrusion of Glen Coe and the great swarm of north-east dykes. C. T. C., H. B. M., E. B. B.

Certain early felsites along the northern front of the Cauldron-Subsidence have already been referred to (Figs. 23, 24, pp. 156, 158). They are never found cutting the Fault-Intrusions, and they have sometimes suffered from shearing in the same manner as the Early Fault-Intrusion. In Fig. 23 two are seen in close association with branches of the Boundary-Fault. In Fig. 24 their distribution seems random.

Other felsites of similar type occur in Garbh Bheinn above Loch Leven, but may belong to a later period than the Fault-Intrusion since they sometimes adopt the N.E. direction characteristic of the Etive Swarm. They are not numerous, and are cut by the porphyrites with which they come in contact. E. B. B.

A few dykes of quartz-porphyry, felsite and hornblende-andesite cut the lavas within the cauldron. Some are traversed by the N.E. dykes, and they do not enter the Fault-Intrusion or Cruachan " Granite ". Their local distribution shows that they belong to the Glen Coe centre. H. B. M.

Other examples, not shown in Fig. 33, come from the area between the two branches of the Glen Coe Fault south of Glen Etive. On the north-east end of Beinn Ceitlein a rhyolite dyke, traced through the quartzite in a north-west direction for 200 yards, is cut by various N.E. dykes of porphyrite and by one of quartz-porphyry. A little further south-east a somewhat similar dyke runs south for 150 yards, and shows beautiful spherulitic structures (S 11460) near the side, which is approximately vertical. It is cut by at least two N.E. porphyrite dykes. Other small rhyolitic intrusions, without the N.E. direction of the Etive Swarm of dykes, and in one case cut by a porphyrite dyke belonging to that swarm, also occur on the same hill end.

Various patches of quartz-felsite and rhyolite, about 800 yd N.N.W. of the ordnance station, 2731 ft, on Beinn Ceitlein, are probably of intrusive nature, and, if so, belong to the early suite now considered. The Fault-Porphyrite chills against one of them. C. T. C.

See also south of Stob Beinn a' Chrùlaiste (Fig. 28). E. B. B.

ETIVE SWARM OF NORTH-EAST DYKES

Two great swarms of north-east dykes are represented in Fig. 18 (p. 129), though owing to lack of space only a small proportion of the dykes actually occurring have been inserted. The Etive Swarm alone concerns us at present. By far the greater number of its members are porphyrites. The rest are mainly microdiorites and quartz-porphyries, as set forth in detail in chapter xvi. Various rock types are often associated in multiple dykes.

The Etive Swarm is interrupted in its centre by the Starav Granite, which, as explained in chapter xiii, is of later date than the N.E. dykes. Even before reaching the margin of the Starav Granite there appears to be a somewhat sudden decrease in the number of the dykes. This relation is rather peculiar, as the diminution occurs within the Cruachan " Granite ", the more marginal portions of which are cut quite freely by the dykes. A possible explanation will be offered presently.

For half a dozen miles south of the Starav Granite, in Sheet 45 (Geol.) and Fig. 18, the direction of the swarm is mainly north-north-east, rather than north-east as elsewhere. Anderson thinks that there is also a tendency for the dykes on this southern side to radiate from the curving margin of the granite when close to it (1937a, p. 508). He is further of the opinion that two dykes of the Etive Swarm penetrate the Starav Granite for a short distance ; but one of these is from the River Kinglas and is petrographically distinct from all other dykes attributed to the swarm (p. 173).

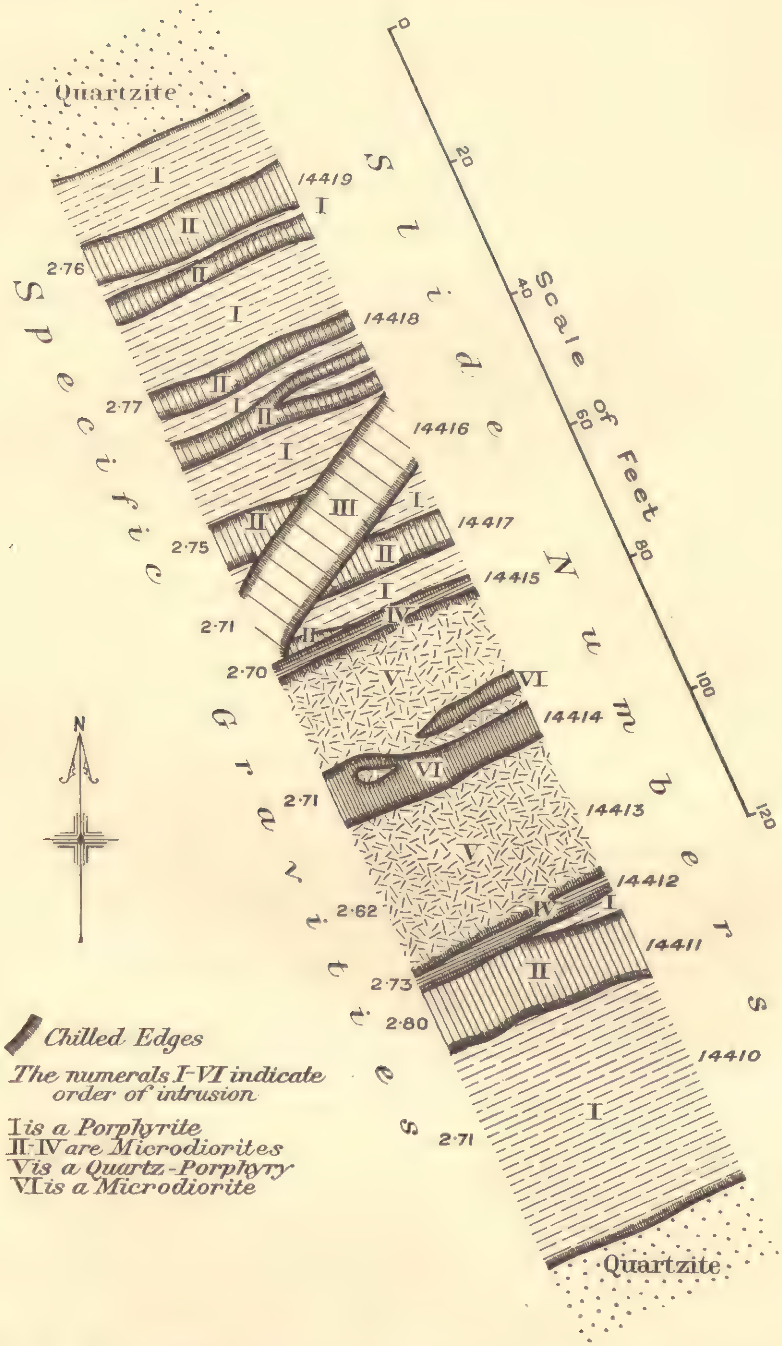


FIG. 34. Map of multiple dyke in the bed of Allt Fhaolain, ½ mile above the bridge, Glen Etive

Allusion has been made to the existence of multiple dykes in the Etive Swarm. The most striking example is a multiple dyke (S 14410-9) that has been traced for a mile and a half into Allt Fhaolain from the south-west. Fig. 34 illustrates its complexity. The order of injection of two dykes in contact has been determined here, as elsewhere, by noting which dyke presents a chilled edge to its neighbour. Chilling of the margins of the dykes is a conspicuous phenomenon throughout the whole district, and it has been found that when a dyke-fissure has been injected at two or more times, the marginal portion of an earlier dyke is very rarely separated from the country rock to allow of the entry of a later. Accordingly it is a very exceptional and local circumstance to find two chilled edges in contact.

H. B. M.

The example given in the last paragraph shows the difficulty of arriving at any generalisation concerning the sequence of the various types of dykes *inter se*. As a further illustration, one may note the behaviour of the quartz-porphyry dykes south-east of Dalness. In various places they cut into, or are chilled against, porphyrite dykes ; but in other places the reverse relations have been observed. A quartz-porphyry in the River Etive half a mile east-north-east of Alltchaorunn is chilled against a parallel dark grey more basic dyke on its north-west side, and about two-thirds of a mile south of Alltchaorunn the same quartz-porphyry dyke intrudes into a porphyrite ; but further south again, in an exposure nearly a mile east of Stob Dubh, the middle of this quartz-porphyry is cut by a more basic dyke. Another quartz-porphyry dyke, three-quarters of a mile slightly south of west of Meall Garbh, and two similar dykes, on the east side of Beinn Ceitlein, are all distinctly cut by porphyrite dykes.

Two quartz-porphyry dykes cross the flinty crush-rock associated with the inner branch of the Glen Coe Boundary-Fault south-east of Dalness, without being crushed or thrown by it ; and one of them can also be traced without any displacement across the outer branch on Beinn Ceitlein. C. T. C.

Several examples of quartz-porphyry dykes cut by porphyrites might be cited from the north-eastward continuation of the Dalness district. Another relation commonly observed is the cutting of other dykes by " pock-marked " microdiorites. The pock-marks which characterise these late dykes are little pits due to the weathering out of chloritic pseudomorphs after rhombic pyroxenes. Albitised pyroxene-microdiorites are well developed in the neighbourhood of Stob Mhic Mhartuin, and are constantly seen to cut the more normal porphyrites. E. B. B., G. W. G.

That there should be an irregularity in the sequence of dyke-types, and that quartz-porphyry dykes, for instance, should be later than some of the porphyrites and earlier than others, is in keeping with the evidence already given in chapter xiii regarding the relations of the dykes to the Meall Odhar Granite. It will be remembered that this granite seems to coalesce with a quartz-porphyry dyke, is cut by many porphyrite dykes, and cuts a few. C. T. C.

The injection of the dykes bears witness to a redistribution of earth-stresses, which, taking place after all subsidence of the Glen Coe block had ceased, brought about an important modification of the original outline of the cauldron amounting to an elongation normal to the direction of the dykes. The dykes have added their own width to the cross-section of the country which they traverse. This feature is brought home by a consideration of Figs. 35 and 36. H. B. M.

In the River Etive, a little above Alltchaorunn, thirty-one dykes were encountered in a distance of 1133 yd (measured at right angles to their strike), and the aggregate width of these dykes amounts to 335 yd. Assuming this an average for the district, although such an assumption probably gives too high a figure, the major diameter of the Glen Coe Cauldron owes 2½ of its 9 miles of length to the insertion of the Etive Swarm of dykes. (For other measurements, see Anderson 1937a, p. 509.) C. T. C.

Two main features call for interpretation. The parallelism of the dykes, and the concentration with reference to the Etive centre.

The N.E. direction, so characteristic of the dyke phase, is perhaps foreshadowed in the elongation of the Etive boss and its alignment with the Glen Coe Cauldron (*cf.* Richey, *in* Sum. Prog. 1915, pp. 36, 37). Be this as it may, the parallel N.E. dykes bespeak a period when the Etive igneous centre was involved in some terrestrial readjustment affecting a much larger region. The stress as transmitted to the Etive district must have been of the nature of relative tension or, in other words, marked relief of pressure. This, in the presence of magma under suitable conditions of hydrostatic pressure, led to the formation of dykes orientated at right angles to the direction of least compression.

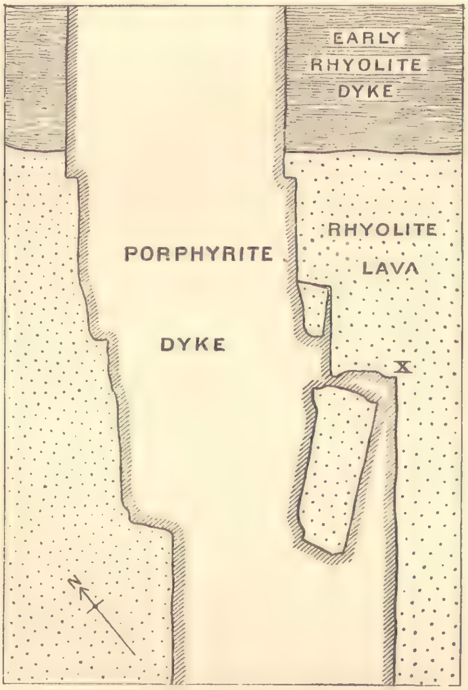


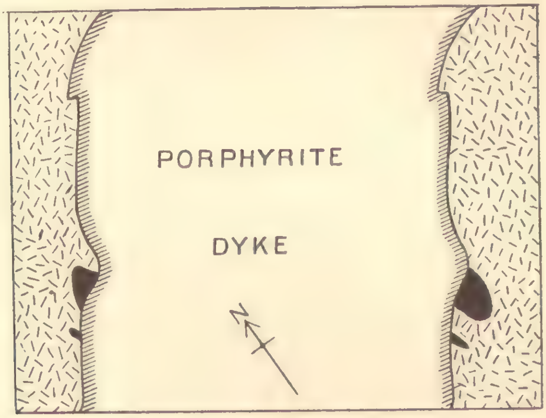
FIG. 35. Map of porphyrite dyke traversing rhyolites at the foot of the northern front of Buachaille Etive Beag

The walls of country-rock are counterparts the one of the other

The fact that the dykes are not all of one epoch, but constantly cut one another with chilled edges, shows that the growth of the regional stress was maintained over a long period. The introduction of the dykes gave intermittent relief to the growing " tension."

The concentration of the Etive Swarm is easy to understand. The intrusion of the Meall Odhar Granite, intervening at an early stage of the dyke phase, and that of the Starav Granite, coming at the close of the same, afford almost a demonstration of the existence, during the whole of the dyke phase, of a large body of unconsolidated magma in the pipe extending from the Cruachan " Granite " down to the general magma basin below. This unconsolidated magma would be incapable of resisting tensional stresses, and its weakness would be a quite sufficient cause to locate the Etive Dyke-Swarm. Probably the dykes were injected from the pipe rather than from the molten reservoir beneath.

C. T. C., H. B. M., E. B. B.



(about $\frac{1}{24}$ natural size)

FIG. 36. Map of porphyrite dyke traversing Moor of Rannoch " Granite " in bed of River Etive, 500 yd above Kingshouse (Sheet 54, Geol.)

Two basic lumps have been bisected

One further point demands explanation : we find the outlying portions of the Cruachan " Granite " cut by dykes as freely as the surrounding schists, but the inner portion, near the edge of the Starav Granite, appears for the most part to have escaped. This suggests that the unconsolidated subterranean magma, which located the Etive Swarm of dykes, existed in the form of peripheral ring-dykes, or ring-bosses, and not of great central bosses filling subterranean cauldrons. The Meall Odhar ring-dyke of granite is a case in point, for it is almost certainly connected with a north-east quartz-porphyry dyke (p. 172), which is found outside, but not inside, the partial ring.

To realise the significance of this conception, one has merely to consider what would have taken place had the regional "tensions," which led to the production of the Etive Swarm, come into being before the consolidation of that irregular ring-dyke, the Fault-Intrusion of Glen Coe. It is obvious that a swarm of dykes would have originated, extending outwards on either side from the ring of Fault-Intrusion, and that few if any of the dykes would have penetrated within the circumference of the boundary-fault. In like manner had the " tensions " been communicated to the district, when the Inner " Granite " of Ben Nevis was in its present situation and still liquid, the Ben Nevis Swarm of dykes would have been excluded from the lavas and schists surrounded by the granite. Now although the Inner " Granite " of Ben Nevis did not rise to its present position till after the intrusion of the great majority of the Ben Nevis dykes, we do find the central lavas and schists free from dykes. It is reasonable therefore to suggest that the dyke-swarms of Etive and Ben Nevis, each with its central region of discontinuity, have proceeded from ring-dykes, of which the Meall Odhar Granite may be taken as a type.

In chapter xiv Maufe refers the immunity of the central schists and lavas of Ben Nevis to another cause (p. 184), but his account was written before the explanation outlined above had been thought of, and there was no subsequent opportunity for reconsideration. The ring-dyke theory of the location of centrally discontinuous dyke-swarms has a further application in Ben Nevis : it satisfactorily accounts for the observation that the few dykes of the swarm which are later than the Inner "Granite" do not enter beyond its marginal portions.

E. B. B.

BEN NEVIS SWARM OF NORTH-EAST DYKES

The Ben Nevis Swarm of dykes is so closely comparable with the Etive Swarm that we need not enter into detail in regard to it (Fig. 18, p. 129) ; as minor points of difference we may note that the course of the dykes seems to be somewhat more east of north-east than that of the Etive dykes, and that microdiorites are about as abundant as porphyrites.

The relations of the dykes to the Outer and Inner "Granites" of Ben Nevis, and to the lavas and underlying schists which form the central portion of the mountain, have already been discussed in chapter xiv. Anderson's discovery in Sheet 62 (Geol.) of early members of the swarm forming a small group running east-north-east and cut off by the Outer "Granite" is a welcome addition to our knowledge (p. 179) since the first edition of this memoir appeared. The explanations offered above in regard to the origin of the Etive dykes are equally applicable in the present instance.

H. B. M.

DYKES NORTH-WEST OF LOCH LINNHE

North-west of Loch Linnhe there are various dykes which probably belong to the Lower Old Red Sandstone period. Notable among them are certain broad felsite dykes well developed in the vicinity of Glen Tarbert. In most of their course within Sheet 53 they run in a general east-north-east direction (p. 190), and are crossed by west-north-west basaltic dykes of presumably Tertiary age. West of Allt a' Choire Dhuibh three of the felsite dykes turn so as to run west-north-west, and one of them is followed by a later basaltic dyke which chills against its more acid companion.

These felsite dykes range up to about 20 ft in thickness, and as they weather with a terra-cotta hue they often make conspicuous objects. Both in the field and under the microscope they recall the acid intrusions of the Old Red Sandstone rather than of the Tertiary period. They freely cut the Strontian "Granite" in Sheet 52 (Geol.), and also other minor masses of plutonic rock with which they happen to come in contact.

E. B. B.

CHAPTER XVII

ROCKS OF LOWER OLD RED SANDSTONE AGE
PETROLOGY OF IGNEOUS ROCKS

Classification and Chemistry

In the 1916 edition of this memoir a rather full discussion is provided of the origins of the petrographical classifications adopted in it for descriptive purposes. This discussion is still available in libraries for consultation, and is not here repeated.

The following SiO_2 percentages have been chosen as separating rocks of different degrees of basicity and acidity :

Ultrabasic . 45 . Basic . 55 . Intermediate . 65 . Acid . 75 . Ultra-acid

Within each of these compositional divisions a three-fold textural grouping is found convenient, namely plutonic, hypabyssal and volcanic. The same three terms can, of course, quite properly be employed in reference to field-relations, rather than texture. Accordingly the meaning of each of them depends upon the context in which it is used. Thus all the dykes of the Ben Nevis and Etive Swarms are hypabyssal intrusions ; but not quite all of them are of hypabyssal texture : some few, especially narrow examples, are of volcanic texture throughout ; while all have chilled selvages, which also are volcanic in the textural sense. Similarly the chilled edges of the plutonic Inner " Granite " of Ben Nevis and of the An t-Sròn " Granite " of Glen Coe are rhyolites or andesites of volcanic textural type.

An important point emphasised by Nockolds and Mitchell is that, over a wide range of composition, the Devonian (that is Old Red Sandstone) plutons, dykes and lavas of Scotland show very similar chemical variety (1948, p. 533). As yet, however, no ultrabasic lava has been collected, nor any with an olivine-augite concentration equal to that of the kentallenites (Anal. 2, Table 2). Still, the Taynuilt basalt lava (Anal. 3) is very close in composition to the Ardsheal basalt intrusion (Anal. 4), which latter Walker found to be a variety of adjoining kentallenite.

Tables 2 and 3 record 33 analyses from Sheet 53 and its natural extensions (Anals. 3, 6, 9, 17, 31 are from Sheet 45 to the south, and 23 from Sheet 54 to the east). Strontian analyses (4, Fig. 18, p. 129) from Sheet 52 to the west are not included, since a memoir on that district is in preparation ; and many others, especially from the Garabal Complex well to the south-east (9, Fig. 18), are also omitted, because it has been thought advisable to present a chemical discussion of the whole South-West Highland suite as a separate publication (Bailey 1958).

One aim of this separate publication has been a comparison of average analyses of Devonian igneous rocks from the South-West Highlands with their Carboniferous and Tertiary counterparts taken from elsewhere in Scotland. The average analyses employed have been arrived at by averaging all suitable analyses between silica-percentage limits of 40-45, 45-50, and so on. A sample set of the values obtained by this arithmetical averaging is marked by crosses on Fig. 37. It is obvious at once that in the ultrabasic and basic divisions there is great scatter of individual composition ; but the fact that the averages lie along a comparatively simple curve encourages the belief that they have considerable significance. Compositional scatter is a well-known feature in analyses of ultrabasic and basic igneous rocks all the world over.

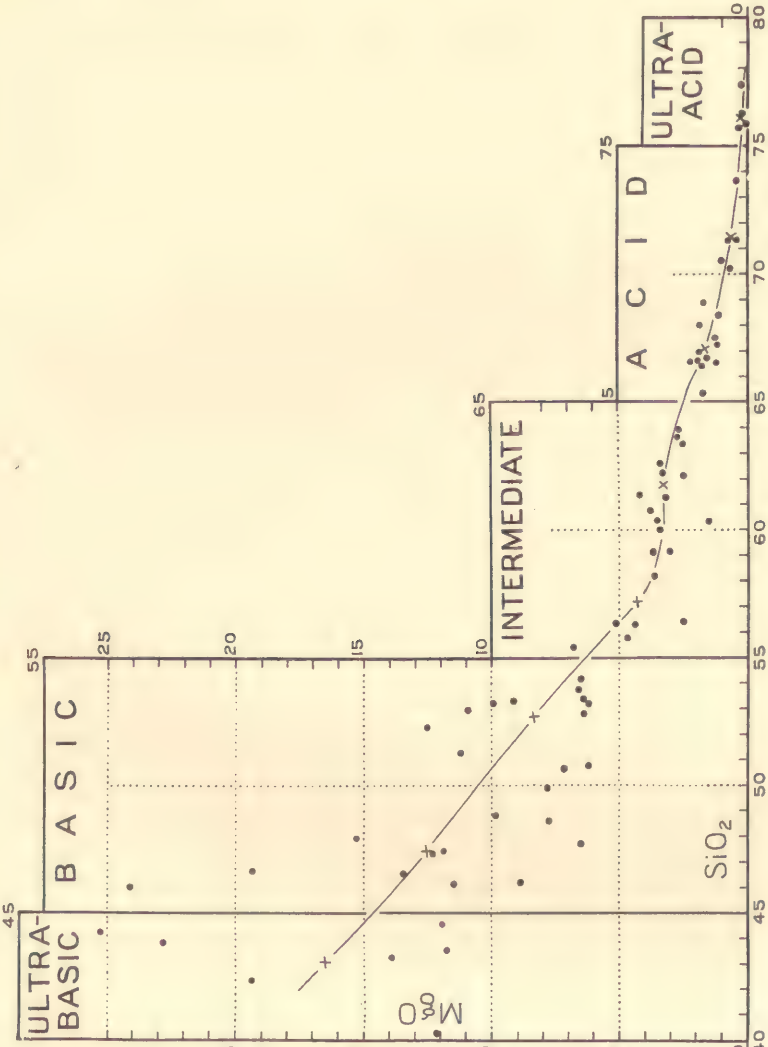


FIG. 37. Graph comparing MgO and SiO_2 percentages of individual Devonian igneous rocks of South-West Highlands. Crosses correspond with averages used in Fig. 37

The comparisons illustrated in Fig. 38 reproduce for the most part features noted years ago by Elder (1935). He summarised his conclusions as follows: " As might have been expected, this renewed study has brought out very clearly the well-known calc-alkali character of the Devonian and Tertiary as compared with the Carboniferous magma. It has also indicated a distinctly magnesian tendency in the Devonian magma, and a ferriferous tendency in the Tertiary magma ".

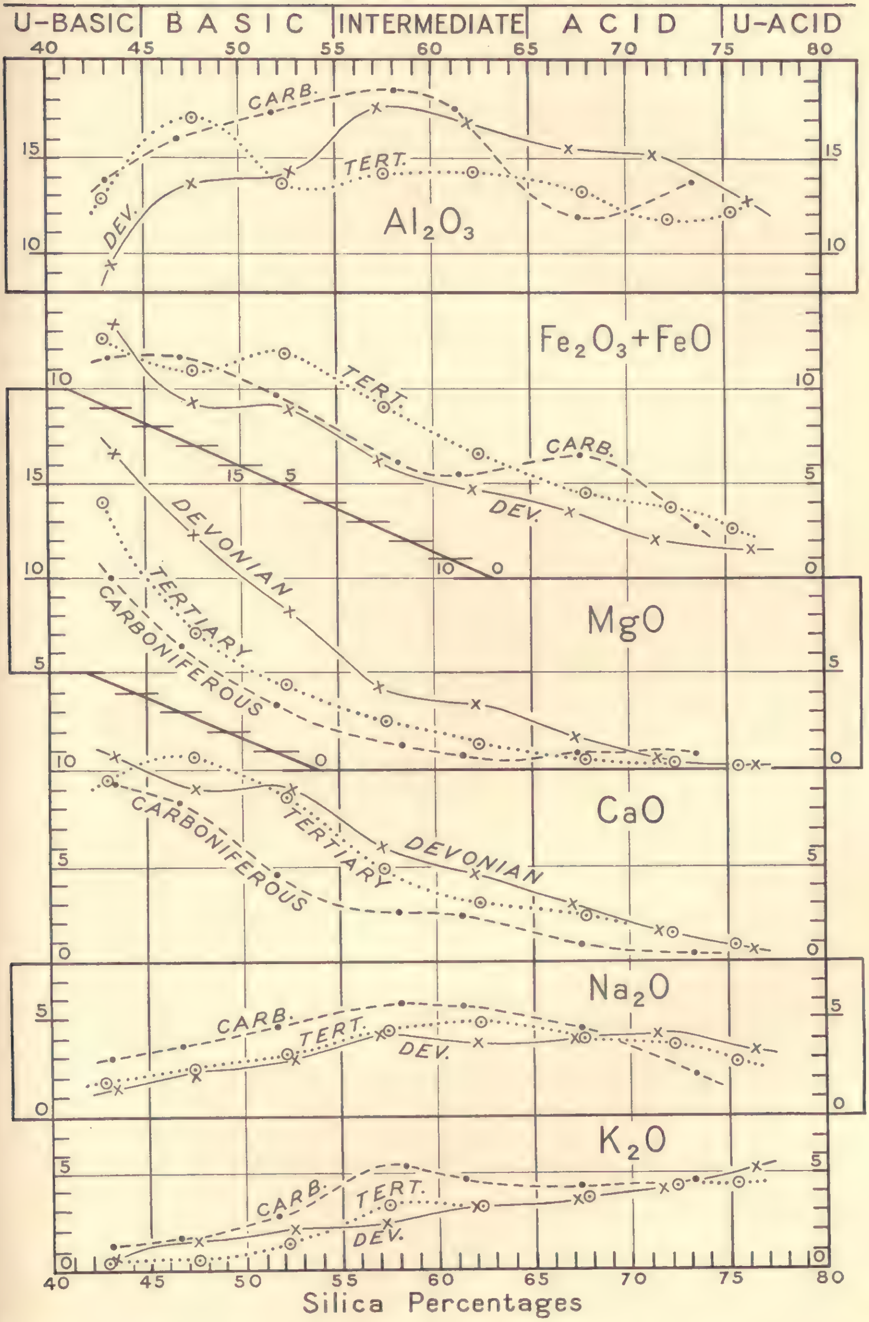


FIG. 38. Graphs comparing average analyses of igneous rocks spaced according to SiO_2 percentages. Tertiary and Carboniferous for all Scotland, Devonian for South-West Highlands

TABLE 2

Analyses of Devonian Igneous Rocks of Sheet 53, 45 and 62 (Geol.)

	ULT.-B.	BASIC						INTERMEDIATE										
	1	2	3	4	5	6	7	8	9	10 (see 13)	11	12	13 (see 10)	14	15	16	17	18
SiO_2	40·26	48·00	49·86	50·60	50·73	53·05	53·22	56·25	56·50	59·11	59·25	59·43	60·05	60·45	60·80	61·49	61·50	62·21
Al_2O_3	15·74	12·52	16·33	14·67	17·08	16·96	17·20	16·30	21·15	17·85	17·30	17·24	18·55	19·89	16·25	14·98	17·35	14·43
Fe_2O_3	3·44	8·74	3·62	2·81	4·59	2·95	2·64	1·60	1·55	1·78	1·15	2·58	0·93	1·76	1·70	1·51	1·27	1·77
FeO	7·95		4·34	6·47	4·06	5·40	4·84	5·05	3·70	3·24	4·07	3·24	3·41	2·27	3·38	3·84	3·87	3·65
MgO	12·09	15·26	7·80	7·04	6·12	6·15	6·33	5·12	2·55	3·85	3·60	2·92	3·46	1·54	3·72	3·22	4·22	5·66
CaO	12·03	7·94	6·47	10·05	7·32	7·45	6·79	6·55	6·15	5·05	4·95	5·14	5·44	4·04	4·75	4·56	3·80	4·43
Na_2O	2·25	3·11	3·42	3·13	3·55	3·36	2·38	4·13	4·37	4·10	4·45	4·11	3·84	4·77	4·05	3·59	2·38	2·65
K_2O	1·36	2·68	2·10	2·65	1·18	1·45	4·12	2·02	2·56	3·06	2·50	2·53	2·72	3·53	3·05	2·80	2·94	2·75
H_2O+	1·75	1·36	2·77	0·50	2·00	1·10	0·61	0·95	0·65	0·73	0·50	0·84	0·35	0·70	0·60	1·68	1·00	0·66
H_2O-	0·48		1·25	0·30	0·33	0·60	0·19	0·10	0·15	0·11	1·00	0·33	0·05	0·45	0·30	0·23	0·50	0·40
TiO_2	2·42	0·22	1·06	1·25	1·90	0·92	0·69	0·90	0·45	0·30	0·70	1·11	0·42	0·30	0·90	0·96	0·75	0·88
P_2O_5	0·04	—	0·54	0·24	0·35	0.54	0·28	0·40	0·22	0·14	0·21	0·26	0·29	0·23	0·28	0·32	0·17	0·20
MnO	0·03	—	0·40	0·23	0·20	0·20	0·25	0·40	tr.	0·05	0·15	0·20	0·16	tr.	0·10	0·21	0·07	0·23
CO_2	0·03	—	0·23	nil	0·82	nil	0·57	nil	nil	—	nil	0·06	—	nil	nil	0·92	nil	0·06
Cl	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·03	—	—
S	nil	—	—	nil	—	—	—	—	0·08	0·19	—	—	—	tr.	—	—	—	—
(Ni,Co)O	—	—	nt. fd.	—	nt. fd.	—	nt. fd.	—	—	—	—	nt. fd.	—	—	—	nt. fd.	—	nt. fd.
BaO	—	—	0·10	—	0·07	—	0·08	—	—	0·23	—	0·13	—	—	—	0·11	—	0·07
ZnO	—	—	—	—	—	—	—	—	—	—	—	—	0·27	—	—	—	—	—
Li_2O	—	—	tr.	—	nt. fd.	—	tr.	—	—	—	—	nt. fd.	—	—	—	nt. fd.	—	nt. fd.
Total	99·87	99·83	100·29	99·94	100·30	100·13	100·19	99·77	100·08	99·70[1]	99·83	100·12	99·94	99·93	99·88	100·45	99·82	100·05
Sp.Gr.	3·19	2·95	2·76	3·00	2·82	2·86	2·85	2·81	—	—	2·71	2·75	—	2·64	2·76	2·71	2·76	2·76

[1] After subtracting 0·09 for S

1 : Appinite ; Ardsheal Hill. **2** : Kentallenite ; Kentallen. **3** : Olivine-basalt with orthoclase ; lava, Taynuilt, Lorne. **4** : Olivine-basalt with orthoclase ; intrusion, Ardsheal Hill. **5** : Hypersthene-basalt ; lava, Glen Coe. **6** : Biotite-diorite with hornblende and augite ; basic phase of Beinn a' Bhuiridh (Cruachan Quarry) Diorite. **7** : Monzonite ; Glen Creran. **8** : Banatite ; Inner non-porphyritic Subzone 3 of Outer "Granite," Ben Nevis. **9** : Tonalite ; intermediate phase of Beinn a' Bhuiridh (Cruachan Quarry) Diorite. **10** : Tonalite ; Outer "Granite," Ballachulish (see **13**). **11** : Banatite ; Outer non-porphyritic Subzone 1 of Outer "Granite," Ben Nevis. **12** : Banatite-porphyrite ; Fault-Intrusion, Glen Coe. **13** : Tonalite ; Outer "Granite," Ballachulish (see **10**). **14** : Hornblende-porphyrite ; dyke, Ben Nevis Swarm, W. of Ballachulish Pluton. **15** : Banatite ; Mid non-porphyritic Subzon e 2 of Outer "Granite," Ben Nevis. **16** : Hornblende-andesite ; lava, Glen Coe. **17** : Hornblende-andesite ; lava, contact-altered in Beinn a' Bhuiridh screen. **18** : Kersantitic microdiorite ; dyke, Etive Swarm, Glen Etive.

TABLE 3

Analyses (continued), Sheets 53, 45, 54 *and* 62 *(Geol.)*

Norwegian

	ACID													ULTRA-ACID		TRONDHJEMITES		
	19	**20** (see **25**)	**21**	**22**	**23**	**24** (**28, 30**)	**25** (see **20**)	**26**	**27**	**28** (**24, 30**)	**29**	**30** (**24, 28**)	**31**	**32**	**33**	**A**	**B**	**C**
SiO_2	65·30	65·72	66·50	66·71	66·91	67·30	67·78	68·02	68·40	70·27	71·35	71·70	73·70	75·71	76·14	70·30	71·95	72·11
Al_2O_3	15·20	15·49	15·15	15·33	15·09	16·50	16·64	14·16	17·21	15·52	13·68	16·81	13·62	12·25	11·91	15·36	15·76	15·25
Fe_2O_3	2·49	2·35	1·34	1·46	1·70	1·20	1·07	1·82	tr.	0·90	1·75		0·48	1·23	1·26	0·56	0·76	0·64
FeO	2·41	2·07	2·39	2·26	1·95	1·98	1·74	1·95	0·92	0·94	0·97		1·28	0·31	0·25	2·37	0·03	0·84
MgO	1·80	1·23	1·88	1·53	2·02	1·27	1·19	1·91	1·03	0·67	0·84	0·47	0·32	0·20	0·13	1·03	0·31	0·38
CaO	3·05	2·69	3·15	2·72	3·27	2·85	2·38	2·81	3·05	1·60	1·85	2·42	0·94	0·61	0·47	3·52	1·65	1·98
Na_2O	4·13	4·49	3·90	3·67	4·16	4·70	4·27	3·90	4·48	4·45	3·75	9·00	4·05	3·79	3·37	4·30	6·63	5·43
K_2O	3·37	4·38	3·68	3·96	3·16	2·75	3·48	3·92	2·88	4·16	4·36		4·85	4·73	5·30	1·45	2·22	2·04
H_2O+	0·81	0·49	0·90	0·28	0·56	0·50	0·48	0·56	0·30	—	0·51	—	Nil	0·52	0·30	0·79	0·42	0·66
H_2O-	0·19	0·12	0·20	0·88	0·14	0·20	0·30	0·20	0·12	—	0·19	—	0·55	0·08	0·36	0·05		0·03
TiO_2	0·83	0·61	0·55	0·69	0·67	0·30	0·36	0·63	0·28	0·31	0·47	—	0·36	0·21	0·15	0·35	0·08	0·17
P_2O_5	0·23	0·43	0·18	0·19	0·17	0·16	0·12	0·16	0·14	0·17	0·11	—	tr.	0·06	0·05	0·12	—	0·06
MnO	0·12	0·04	0·10	0·18	0·18	nil	—	0·22	—	0·04	0·18	—	nil	0·10	0·19	0·04	—	0·02
CO_2	tr.	—	nil	0·15	nt. fd.	nil	—	nt. fd.	—	—	nt. fd.	—	nil	0·19	0·26	0·13	—	0·22
S	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·03	—	0·06
FeS_2	—	—	—	—	—	—	—	—	1·08	—	—	—	—	—	—	—	—	—
(Ni,Co)O	nt. fd.	—	—	nt. fd.	nt. fd.	—	—	nt. fd.	—	—	nt. fd.	—	—	nt. fd.	nt. fd.	—	—	—
BaO	0·11	0·19	—	0·10	0·05	—	—	0·06	—	—	0·05	—	—	0·08	0·01	tr.	—	0·03
Li_2O	nt. fd.	—	—	?	nt. fd.	—	—	nt. fd.	—	—	tr.	—	—	?	nt. fd.	—	—	—
Total	100·04	100·30	99·92	100·11	100·03	99·71	99·81	100·32	99·89	99·03	100·06	100·40	100·15	100·07	100·15	100·40	99·81	99·92
Sp. Gr.	2·70	—	2·68	2·69	2·69	2·67	—	2·69	—	—	2·65	—	2·62	—	—	2·71	2·64	2·68

19 : Biotite-hornblende-porphyrite ; Early Fault-Intrusion, Glen Coe. **20** : Granite ; Inner Granite, Ballachulish (see **25**). **21** : Granite ; porphyritic subzone of Ben Nevis Outer "Granite". **22** : Hornblende-porphyrite ; dyke, Etive Swarm, Glen Etive. **23** : Trondhjemite ; Moor of Rannoch "Granite". **24** : Trondhjemite ; Inner "Granite," Ben Nevis (see **28, 30**). **25** : Granite ; Inner Granite, Ballachulish (see **20**). **26** : Adamellite ; Northern Lobe, Cruachan "Granite". **27** : Trondhjemite ; "White Granite," Ballachulish. **28** : Granite ; Inner "Granite," Ben Nevis (see **24, 30**). **29** : Granite ; Starav Granite. **30** : Trondhjemite ; Inner "Granite," Ben Nevis (see **24, 28**). **31** : Binary Granite ; referred to Meall Odhar Granite. **32** : Rhyolite ; lava, Glen Coe. **33** : Quartz-porphyry ; dyke, Etive Swarm, Glen Etive. **A, B, C** : Three Norwegian Trondhjemites to compare with **23, 24, 27, 30.**

Further details regarding Tables 2, 3 are given on pp. 208-9.

List of Analyses

1. Appinite, unusually basic ; Ardsheal Hill, W. of Ballachulish Pluton. Anal. W. H. Herdsman. Quoted from F. Walker (1927, p. 154)—p. 214.
2. Kentallenite (S 7053) ; Kentallen quarry, W. of Ballachulish Pluton. Anal. J. J. H. Teall. Quoted from J. J. H. Teall (Ann. Rep. 1897, p. 22).—p. 212.
3. Olivine-basalt with orthoclase (S 9628) ; lava, N.W. side of Cruach Ard-dhuine, 3 miles S.S.W. of Taynuilt (Sheet 45). Anal. E. G. Radley. Quoted from 1st edition.—p. 233.
4. Olivine-basalt with orthoclase ; intrusion, Ardsheal Hill, W. of Ballachulish Pluton. Anal. W. H. Herdsman. Quoted from F. Walker (1927, p. 154).—p. 213.
5. Hypersthene-basalt (S 14408) ; lava, right bank of stream, ½ mile S.S.W. of Loch Achtriochtan, Glen Coe. Anal. E. G. Radley. Quoted from 1st edition.—p. 233.
6. Biotite-diorite with hornblende and augite ; basic phase of Beinn a' Bhuiridh (Cruachan Quarry) Diorite, stream S. of large crag W. of Allt Cruachan (Sheet 45). Anal. W. H. Herdsman. Quoted from J. G. C. Anderson (1937a, p. 518).—p. 191.
7. Monzonite, with hornblende (S 14113) ; River Creran, ⅜ mile E. of Salachail, Glen Creran. Anal. E. G. Radley. Quoted from 1st edition.—p. 213.
8. Banatite ; Inner, coarse, non-porphyritic member of Ben Nevis Outer " Granite " (Subzone 3), at mouth of tunnel leading from hydro-electric surge-chamber. Anal. W. H. Herdsman. Quoted from J. G. C. Anderson (1935b, p. 257).—p. 222.
9. Tonalite ; intermediate phase of Beinn a' Bhuiridh (Cruachan Quarry) Diorite (Sheet 45). Anal. W. H. and F. Herdsman. Quoted from S. R. Nockolds (1934, p. 315).
10. Tonalite ; Outer " Granite," Ballachulish Pluton (see **13**). Anal. I. D. Muir. Quoted from I. D. Muir (1953a, p. 184).—p. 225.
11. Banatite ; Outer, fine, non-porphyritic member of Ben Nevis Outer " Granite " (Subzone 1), 150 yd below light-railway bridge, Allt na Caillich (Sheet 62). Anal. W. H. Herdsman. Quoted from J. G. C. Anderson (1935b, p. 257).—p. 222.
12. Banatite-porphyrite (S 14117) ; Fault-Intrusion of Glen Coe, Stob Mhic Mhartuin, 1¼ mile N.W. of Altnafeadh. Anal. E. G. Radley. Quoted from 1st edition.—p. 218.
13. Tonalite ; Outer " Granite," Ballachulish Pluton (see **10**). Anal. W. H. Herdsman. Quoted from F. Walker (1924, p. 554).—p. 225.
14. Hornblende-porphyrite ; N.E. dyke, Ben Nevis Swarm, Ardsheal Hill, W. of Ballachulish Pluton. Anal. W. H. Herdsman. Quoted from F. Walker (1927, p. 154).—p. 230.
15. Banatite ; Mid non-porphyritic member of Outer " Granite " of Ben Nevis (Subzone 2), beside light railway between Allt a' Mhuilinn and Allt na Creige Duibhe (Sheet 62). Anal. W. H. Herdsman. Quoted from J. G. C. Anderson (1935b, p. 257).—p. 222.
16. Hornblende-andesite (S 14576) ; lava, corrie between Stob Coire nan Lochan and Bidean nam Bian, Glen Coe. Anal. E. G. Radley. Quoted from 1st edition.—p. 234.
17. Hornblende-andesite ; lava, contact-altered in Beinn a' Bhuiridh Screen, Allt Coire Ghlais, a little above junction with Allt Coire Chreachainn (Sheet 45). Anal. W. H. Herdsman. Quoted from J. G. C. Anderson (1937a, p. 521).—p. 176.
18. Kersantitic microdiorite (S 14406) ; N.E. dyke, Etive Swarm, roadside E.N.E. of Alltchaorunn, Glen Etive. Anal. E. G. Radley. Quoted from 1st edition.—p. 229.
19. Biotite-hornblende-porphyrite (S 14109) ; Early Fault-Intrusion of Glen Coe, 2½ miles N.W. of Altnafeadh. Anal. E. G. Radley. Quoted from 1st edition.—p. 215.
20. Granite ; Inner Granite, Ballachulish Pluton (see **25**). Anal. I. D. Muir. Quoted from I. D. Muir (1953a, p. 184).—p. 225.
21. Granite ; Porphyritic member of Ben Nevis Outer " Granite," just outside tunnel intake Allt an t-Sneachda (Sheet 62). Anal. W. H. Herdsman. Quoted from J. G. C. Anderson (1935b, p. 257).—p. 223.
22. Hornblende-porphyrite (S 14398) ; N.E. dyke, Etive Swarm, River Etive above falls, ¼ mile E. of Dalness. Anal. E. G. Radley. Quoted from 1st edition.—p. 230.
23. Trondhjemite (S 14110) ; Moor of Rannoch " Granite," road-cutting to shooting lodge ½ mile from Kinghouse Hotel (Sheet 54). Anal. E. G. Radley. Quoted from 1st edition.—p. 225.
24. Trondhjemite ; Inner " Granite," Ben Nevis (see **28, 30**) tourist path. Anal. W. H. Herdsman. Quoted from J. G. C. Anderson (1935b, p. 257).—p. 223.
25. Granite ; Inner Granite, Ballachulish Pluton (see **20**). Anal. W. H. Herdsman. T. R. M. Lawrie (unpublished).—p. 225.
26. Adamellite (S 14112) ; Northern lobe, Cruachan " Granite," River Etive where Allt Fionn Ghlinne enters. Anal. E. G. Radley. Quoted from 1st edition.—p. 221.
27. Trondhjemite ; " White Granite," W. margin of Ballachulish Pluton. Anal. W. H. Herdsman. Quoted from F. Walker (1924, p. 554).—p. 225.

28. GRANITE ; Inner " Granite," Ben Nevis (see **24, 30**). Anal. Geochem. Labs. Quoted from S. R. Nockolds and R. L. Mitchell (1948, p. 574).—p. 223.

29. GRANITE (S 14111) ; Starav Granite, streamlet, ¼ mile a little N. of E. of Coileiter, Glen Etive. Anal. E. G. Radley. Quoted from 1st edition.—p. 222.

30. TRONDHJEMITE ; Inner " Granite," Ben Nevis (see **24, 28**). Allt a' Mhuilinn, ¾ mile N. of Ben Nevis summit. Anal. B. Lightfoot. Quoted from 1st edition—p. 223.

31. BINARY GRANITE ; referred to Meall Odhar Granite, summit of Taynuilt peak, 3611 ft, Ben Cruachan (Sheet 45). Anal. W. H. Herdsman. Quoted from J. G. C. Anderson (1937a, p. 518).—p. 221.

32. RHYOLITE (S 14100) ; lava, Allt Coire Gabhail, at S. end of alluvial flat, 1 mile S.S.W. of River Coe. Anal. E. G. Radley. Quoted from 1st edition.—p. 235.

33. QUARTZ-PORPHYRY (S 14114) ; N.E. dyke running parallel with River Etive, 2 miles E.S.E. of Altnafeadh, Glen Coe. Anal. E. G. Radley. Quoted from 1st edition.—p. 232.

A, B, C. Three Norwegian TRONDHJEMITES : **A** from Mastravarde, Anal. Röer ; **B** from Frenstad, Anal. Damm ; **C** from Skavlien, Anal. Röer, to compare with **23, 24, 27, 30.** Quoted from A. Johannsen (1932, pp. 383, 385).

The main additional point made in Fig. 38 is that, among acid and intermediate rocks, the average Devonian product tends to be richer in Al_2O_3 than the average Tertiary product ; whereas among thoroughly basic rocks the reverse holds good. The high alumina among the acid and intermediate Devonian rocks corresponds with a tendency to develop porphyries and porphyrites in rocks of hypabyssal crystallisation. The drop in Al_2O_3 on the basic side of 57 per cent. SiO_2 occurs in spite of rising CaO ; so that it is clear that rapid increase in MgO in this direction takes more and more of the CaO into the ferromagnesian camp, either in augite or hornblende—a lamprophyric feature.

It is well to realise that the Tertiary hump for Al_2O_3 at 47 per cent. SiO_2, corresponding as it does with a high for CaO, is an average rather than a universal feature. It depends upon a strong representation of the anorthite molecule in rocks such as allivalite, eucrite, highly felspathic olivine-gabbro and the Mull Porphyritic Central Type of dolerite and basalt. These rocks have no close analogues in the Devonian of the South-West Highlands—but the contrast is reduced in emphasis when we recall that the Mull Normal Series, among Tertiary products, does not carry felspar phenocrysts and does not show a hump in its Al_2O_3 curve.

The relatively high K_2O in Devonian basic rocks as compared with Tertiary corresponds with the monzonitic tendency of the former, illustrated by prevalence of biotite.

Elder's use of the word magma in the passage quoted may perhaps be criticised, since many of the analyses concerned probably represent rocks with compositions largely determined by crystal concentration. On the other hand the features to which he draws attention, such as high MgO, characterise rocks through a wide range of SiO_2 percentages, so that it seems justifiable to regard them as in some measure of magmatic character.

In the paper (Bailey 1958), already referred to, a rather complex set of comparisons leads to the suggestion that the basic plutonic rocks of our Devonian suite have crystallised in an augitic facies (*cf.* kentallenite, augite-diorite) or a hornblendic facies (*cf.* appinite) according to the relative dryness or wetness of the parent magma. One supporting circumstance is that all the basic lavas of the district are augitic. It is true that hornblende-andesites are typical among the intermediate lavas ; but their hornblende has obviously been out of equilibrium under near-surface conditions, for it has suffered greatly from resorption. It is further suggested in this paper that the South-West Highland Devonian magma was on the whole wetter than the Hebridean Tertiary magma ; but readers must consult the original if they want to pursue the argument further.

Meanwhile it may be pointed out that Walker (1927, p. 152) and Nockolds (1941, p. 498) had both come to much the same conclusion regarding the augitic and hornblendic plutonic rocks of our district. Also, after this view had been developed by the writer, it received, quite independently, strong experimental support from Yoder and Tilley (1956).

One of the most important petrological contributions furnished by the district is evidence which J. G. C. Anderson has described in relation to gravitational differentiation in intermediate to acid plutons in the Ben Nevis and Etive Complexes. Kynaston and Grabham had already put forward a claim in this direction in the 1916 edition of the memoir ; but Kynaston's observations were confused owing to an important mistake, later corrected by Anderson (pp. 168, 184).

As set out in Fig. 38 the variations with which Anderson was concerned in the intermediate to acid range follow, on the average, roughly linear courses—Anderson has indeed pointed out that Anals. 6, 26, 29 and 31 show very close linear variations, though Anal. 9 does not fit into the scheme at all (1937a, fig. 6, p. 517). If any material consisting of two substances, each itself of constant composition, is sorted out into a number of fractions in which these two substances occur in quite different proportions, the composition of the products will vary in linear fashion. Accordingly it would seem that the intermediate to acid products, here considered, consisted during consolidation of early crystals and residual magma, and that variations of bulk composition have been controlled by relative migration during which the compositions of the early crystal assemblages and of the residual magma have not altered materially. Of course the same result chemically would be attained by hybridisation in varying proportions of two originally separate magmas, that is by mixing instead of unmixing ; but the unmixing explanation seems to meet the field appearances better.

Allusion has often been made to the chilling or quenching of the Fault-Intrusion of Glen Coe and of the Inner " Granite " of Ben Nevis against the cold contents of the cauldron-subsidences which they surround. Additional data are furnished in the sequel in relation to the quenching of permeation products of the former in this critical position (p. 216).

In the 1916 edition several outside analyses were published to enable comparison with those of the local rocks. With increase of local analyses foreign records have now almost been crowded out ; but a place has been reserved in Table 3 for Analyses A, B, C of three trondhjemites from Norway. The intermediate and acid plutonics of our district have commonly a fair proportion of both plagioclase and orthoclase. Where the plagioclase to orthoclase ratio is greater than 2 : 1, the rock is usually intermediate and can be comfortably accommodated as a tonalite. Where it is less than 2 : 1 and yet greater than 1 : 2, the rock is generally acid and can find a position among the adamellites. There are, however, a few acid plutonics in the district, which often seem to have a plagioclase to orthoclase ratio greater than 2 : 1. In the 1916 edition they were grouped as aplodiorite. This name serves quite well to suggest the composition of the rocks concerned ; but it is apt to convey a completely wrong idea as to texture. In the present account the aplodiorites have been transferred to trondhjemite. They are represented by Anals. 23, 24, 27, 30, and among them the most important constitutes much of the Inner " Granite " of Ben Nevis. Comparison of these four analyses with Anals. A, B, C shows that the Scottish examples can only be

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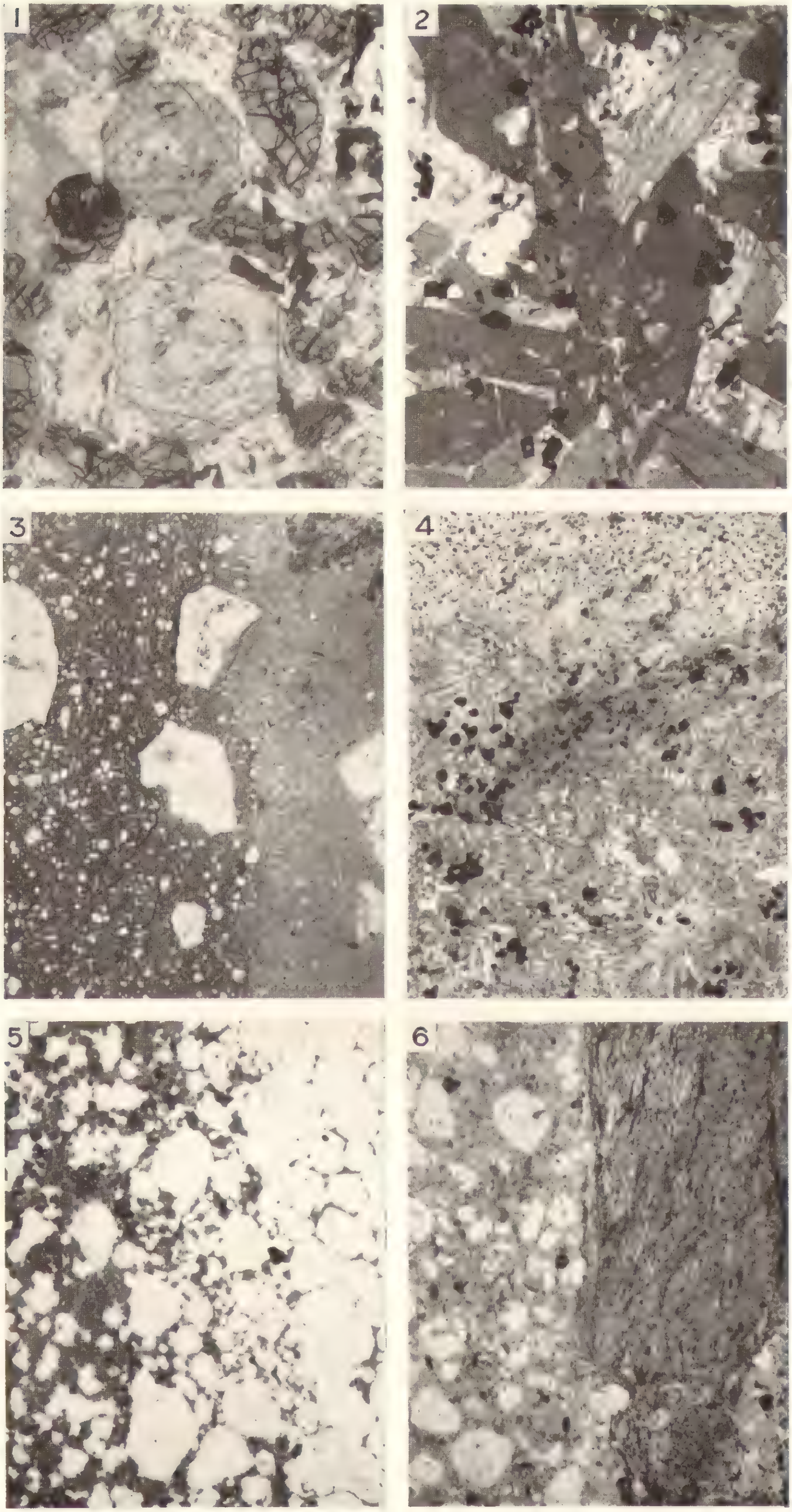


PHOTOMICROGRAPHS OF KENTALLENITE, APPINITE AND ROCKS CONNECTED WITH THE FAULT-INTRUSION OF GLEN COE. × 10 DIA.

regarded as standing on the verge of the trondhjemite group. Their CaO is sufficiently high, but their K_2O is definitely too abundant to be typical.

Just as the name aplodiorite has been abandoned, so also that of aplogranite is replaced by the more easily intelligible term binary granite. Anal. 31 may be classed as belonging to a binary granite, or at any rate to a near approach to the type. The ultra-acid Anals. 32, 33 are more definitely representative, so far as composition is concerned ; but they represent hypabyssal and volcanic specimens.

ULTRABASIC AND BASIC PLUTONIC ROCKS

Cortlandtite.—The name cortlandtite is applied in this memoir to coarse-grained olivine-augite-hornblende rocks which many would call hornblende-picrites. Two small outcrops are shown black and lettered C in Fig. 32, p. 186 ; but they are included with kentallenite, K, in Sheet 53. The more easterly (S 11441) used to be seen in Allt Eilidh surrounded by trondhjemite (S 11363). It is now covered by a fish-pond. The more westerly (S 11442) lies in the tongue of basic rocks extending from the Ballachulish Pluton towards Allt Eilidh, and is surrounded by appinite.

The slice (S 11441) is on the whole beautifully fresh. It consists for the most part of irregular grains of olivine and almost colourless augite set in large poikilitic crystals of brown hornblende. There is also a little rather pale-brown biotite that may be earlier than the hornblende. The olivine is clouded with rod inclusions, similar to what we shall see in the kentallenites. Its partial decomposition has developed a network of magnetite-filled cracks in itself and corresponding sheaves of black cracks traversing adjacent minerals. The augite is almost colourless, and frequently shows lamellar twinning. It rarely makes contact with the olivine, and some crystals are crowded with inclusions due to reaction. The coexistence of abundant fresh augite and primary hornblende is an unusual feature.

The other slice (S 11442) is somewhat similar, but all its augite is reacting to give hornblende, which may be brown or green ; and fresh hypersthene is an important constituent ; while biotite builds a large poikilitic crystal.

EXPLANATION OF PLATE XI

1. Kentallenite, type quarry (S 7053). Olivine, with black cracks ; augite, idiomorphic, grey ; felspar, clear ; biotite, pale or dark. (photo M.2436 ; p. 212).
2. Appinite, N. of Leacantuim, Glen Coe (S 11036). Hornblende, mainly dark ; felspar and quartz, clear. (M.2441 ; p. 215).
3. Junction of flinty crush-rock (left) with chilled Fault-Intrusion (right) at Boundary-Fault, Stob Mhic Mhartuin (S 13403). The minute clear grains in the flinty crush-rock are quartz. The four larger crystals in the same are xenocrysts of felspar derived from the Fault-Intrusion. The four crystals in the Fault-Intrusion are felspar phenocrysts, one showing dark. (M.2444 ; p. 162).
4. Junction of pelitic hornfels (upper third of photo) with *lit par lit* vein (remainder) in xenolith in Fault-Intrusion, taken from quenched zone at Boundary-Fault, An t-Sròn (S 10311). Due to quenching the vein has completed its crystallisation by developing spherulites—right at bottom corner and left at margin against hornfels. (M.2445 ; p. 216).
5. Fault-Intrusion (felspar shows grey) detaching quartz xenocrysts (clear) from quartzite xenolith. Permeation area north of Glen Coe (S 11517b). (M.2440 ; p. 219).
6. Greatly sheared xenolith of basic lava (right), recrystallised with much minute hornblende. It is enclosed in chilled Fault-Intrusion (left), loaded with clear xenocrysts of quartz, and has been carried just inside Cauldron-Subsidence of Glen Coe at An t-Sròn (S 11905). (M.2439 ; p. 217).

Kentallenite (Pl. XI, 1).—The type slice (S 7053) from Kentallen quarry has been described by Teall as follows (Annual Report 1897) :

" The rock is composed of olivine, augite, biotite, plagioclase, orthoclase, magnetite, and apatite. The olivine is fresh, colourless, and is traversed by the usual anastomosing veins of magnetite. It is also, as a rule, crowded with extremely minute and often rod-like inclusions, which give it a cloudy aspect when viewed with low powers [the rods are now commonly thought to be exsolved magnetite]. The sections of the individuals are never bounded by straight lines meeting in sharp angles, but traces of idiomorphism are not uncommon ; in other words, the mineral occurs as grains or crystals with more or less rounded angles. It is present as inclusions, both in augite and biotite, and the felspars are often moulded upon it.

" The augite occurs in grains, crystals, and patches, which vary in size—the forms may frequently be recognised, and the angles are often fairly sharp. The colour in thin slices is pale green, and sections which appear homogeneous in ordinary light often show a beautiful zonal structure under crossed nicols.

" Biotite occurs in large ragged patches, which, in spite of their apparent isolation, often show uniform orientation over large areas. The mineral is of a rich brown colour, approximately uniaxial and strongly pleochroic. It is not only moulded on the augite and olivine, but also occasionally on the felspars, and was therefore one of the last minerals to form.

" The felspars, together with the small amount of biotite, make up the interstitial matter in which the olivines and augites are embedded. Both plagioclase and orthoclase are present in approximately equal quantities, and the former is markedly idiomorphic with respect to the latter. The plagioclase sometimes shows a zonal structure, and probably ranges in composition from labradorite to oligoclase, the acid type predominating. It may be readily distinguished from the orthoclase by its higher refractive index and by the albite twinning. The orthoclase occurs as interstitial matter (mesostasis). Individual patches sometimes show twinning on the Carlsbad plan. The accessory minerals are apatite and magnetite, the latter occurring almost exclusively in the veins that traverse the olivine. All the minerals are remarkably fresh ".

Teall went on to comparison with Brögger's olivine-monzonite type. Later, Hill and Kynaston (1900), introducing the name kentallenite, did not insist upon any definite proportion between plagioclase and orthoclase. Teall's analysis of the type rock is given in Table 2 (Anal. 2, p. 206).

In Kentallen quarry the kentallenite is traversed by occasional intermediate segregations. A conspicuous white patch filling a pocket contains plates of biotite set in any direction and measuring up to an inch and a half across. It is probably what Rosenbusch (1907, p. 170) has called an inclusion on the authority of K. Fürbringer. Rosenbusch has noted fairly frequent pseudomorphs after nepheline, but he was almost certainly mistaken. The rock is a syenite consisting essentially of an allotriomorphic aggregate of microperthitic felspar and subordinate, fresh, rich-brown biotite (S 15874-5). Small idiomorphic apatites and fairly large sphenes are conspicuous accessories, while there is also a very little quartz. Some neighbouring olivines in the kentallenite have been replaced by serpentine with a rim of magnetite followed externally by radiating tremolite. In other cases olivine is replaced by a tremolite-magnetite aggregate often sprouting green biotite. At the same time the original brown biotite of the kentallenite has mostly changed to green with much re-crystallisation. It is not necessary to attribute all this to the acid segregation, since the kentallenite lies within the contact-aureole of the great Ballachulish Pluton. Very likely the segregation vein induced preparatory decompositions, which were later turned to advantage by the Ballachulish Pluton. It is noteworthy that the felspars of the kentallenite near the segregation show clouding of the type commonly met with in contact-altered igneous rocks. The felspars of the segregation also show this effect (in a minor degree) ; but the felspars of the type kentallenite slice (S 7053), away from the vein, are almost free of clouding. The suggestion is that the segregation introduced some material (perhaps containing iron) that made adjoining felspars susceptible to subsequent clouding (*cf.* p. 259).

Another such segregation, occurring as a thin vein, is a biotite-diorite, mostly made of panidiomorphic much-zoned plagioclase, seldom as basic as labradorite, along with a small proportion of allotriomorphic flakes of brown biotite of about the same length as the felspars (S 15873).

The field relations of the other little kentallenite bosses of Sheet 53 have already been detailed in chapter xv with slices duly quoted. Beautifully fresh material is provided in a slice (S 8830) from west of Beinn Sgluich and in others (S 11357, 11360, 11445) from Glen Creran. All these slices closely resemble the type (S 7053), though in two (S 11357, 11360) there is very little orthoclase, while their augite tends to recur in a second generation, sprouting from olivine or moulded on plagioclase. In one also (S 11357) there is a little enstatite. In another slice (S 11361) from Glen Creran olivine is represented by tremolitic aggregates, recalling those described near the segregation vein in Kentallen quarry (see also S 11439) ; while augite is rimmed and crossed by green secondary hornblende. The development of tremolite is perhaps due to the great Cruachan Pluton.

The fine-grained marginal types associated with the Glen Creran outcrops just noticed are particularly interesting, since they prove that the large olivines and augites of the kentallenites were carried in a liquid matrix. Of four slices, only one (S 11438) retains most of its olivine fresh—in crystals bordered externally by a narrow halo of serpentine that separates olivine and matrix. In another (S 11358) some olivine is preserved, but most has gone to serpentine with a concentration of magnetite at the margin (as well as along cracks). Here too there is a serpentine halo. In still another (S 11435), which shows a kentallenitic dyke with very fine groundmass cutting a coarser kentallenite, all olivines are replaced by tremolite-magnetite aggregates, with tremolite extending into a serpentinous halo. Similar aggregates of tremolite, or related amphibole, representing olivine (S 11440), may also extend into manifest cracks crossing the felspathic base. Augite as big crystals in these four slices is relatively fresh. It tends to show internal skeletal perforation such as is generally ascribed to corrosion. It recurs in the groundmass as small prisms or grains. Biotite is almost wanting, while little grains of magnetite are abundant. Here again the tremolite developments may perhaps be referred to contact-action by the Cruachan Pluton.

Turning back to west of the Ballachulish Pluton, we may recall Walker's description of the orthoclase-bearing olivine-basalt intrusion of Ardsheal Hill (Anal. 4, Table 2), which passes laterally into a kentallenite with rather fine matrix. This basalt has large augites ; but its olivines, though darkened with exsolved magnetite, are fewer and smaller than those commonly found in kentallenites. Correspondingly there is a comparative poverty in MgO. Biotite is absent from the groundmass, where instead we find plenty of minute crystals of magnetite. The alkali content agrees with what is found in kentallenites.

We have already followed Walker in comparing the Ardsheal basalt intrusion with the Taynuilt basalt lava (Anal. 3, Table 2 ; S 9628). In this latter, olivine phenocrysts (serpentinised) are big and numerous enough to match those of the kentallenites ; but augite phenocrysts are wanting. In keeping, the analysis shows but little more MgO than is found at Ardsheal. That augite has not developed as phenocrysts is connected with relatively low CaO accentuated by high Al_2O_3, which last shows that a considerable proportion of the CaO has gone to felspar.

Two slices (S 11573-4) represent the unusually basic kentallenite north-east of Sgòr na h-Ulaidh. Both show tremolite-magnetite pseudomorphs after olivine along with some development of irregular green hornblende after augite. The alteration is particularly marked in the relatively fine slice (S 11574), which is from a marginal specimen. It may be attributable either to the Cruachan or the An t-Sròn pluton, since these two are about equidistant from the occurrence.

Biotite-Augite-Diorite and Monzonite.—The biotite-augite-diorites of Sheet 53 had perhaps better be called monzonitic gabbros. They may be described as augite-felspar-biotite-rocks. Their main differences from kentallenite are that olivine is much less important or actually absent, whereas biotite is more abundant and tends to occur in stout flakes of moderate extent, seldom poikilitic, while quartz may be present with granophyric tendency. Apatite remains a conspicuous accessory. The abundance of biotite associated with augite gives the rocks a strongly marked monzonitic character, and in some cases (S 14113, Anal. 7, Table 2) there is enough orthoclase present to warrant the name monzonite without any qualification. Secondary hornblende has been widely developed, and there is occasionally a little brown primary hornblende.

All the six slices in the collection agree closely with the general description given above. For the most part only special features will be referred to below. The occurrences are taken in the order in which they are mentioned in chapter xv dealing with field relations. Grant Wilson recorded chilling in the field, but there is no corresponding specimen.

Rudha Mòr (S 7055). Tremolitic pseudomorphs after olivine. Interstitial quartz.

Ardsheal Hill (S 7054). Some brown hornblende intergrown with biotite. Also green hornblende, probably juvenile.

S. W. of Salachail (S 11362). Some tremolitic aggregates after olivine. Occasional primary hornblende growths about augite. Biotite as always.

E. of Salachail (S 14113 ; Anal. 7, Table 2). Augite largely replaced by pale hornblende which may be juvenile. Biotite abundant. Felspars dirty, but orthoclase appears to serve as base to plagioclases.

W. of Corbhainn (S 11431). Augite largely replaced by pale hornblende. Much micropegmatite.

Glen Ure (S 10125). Undoubted contact-alteration by Cruachan " Granite ". Augite replaced by aggregates of stout prisms of green hornblende. Some aggregate crystallisation of brown biotite. Some clouding of felspars.

Appinite (Pl. XI, 2).—On pp. 167-8 of the 1916 edition of this memoir the following definition was offered of appinite. (The name was based upon the parish of Appin that stretches south from the entrance to Loch Leven ; and it was pointed out that the type appears to be widely distributed in the Highlands.)

" Appinites are the plutonic equivalents of hornblende vogesites and spessartites : they are dark rocks of medium to coarse texture, and mainly composed of green or brown idiomorphic hornblende (either stumpy or acicular) in a groundmass which contains plagioclase, orthoclase, and quartz in variable proportions ; granophyric growths of quartz and orthoclase are common ; where plagioclase is the dominant felspar, quartz may be almost or quite absent ; olivine (as pseudomorphs), augite, and biotite are sometimes present. Decomposition, probably in part juvenile, has often given rise to tremolitic hornblende, chlorite, albite, zoisite, epidote, and calcite ".

Appinites with predominant orthoclase might be classed by some authors as basic or ultrabasic syenites ; and those with predominant plagioclase as basic or ultrabasic diorites.

Quartz is usually about as abundant as felspar. With failure of quartz and felspar the appinites join with hornblendites.

The appinites approach the proterobases including the albitic sub-group called minverite by Dewey (1910, p. 46). They are distinguished mainly owing to the red-brown colour of the hornblende of the proterobases, which is combined with a purplish tint, sometimes very faint, in the augite. Also ilmenite is often a conspicuous accessory in the proterobases, but not in the appinites.

A few comments on Geological Survey slices will suffice. Where brown is not specially mentioned the hornblendes are usually green. For convenience localities are again taken in the same order as in chapter xv where field relations are considered.

Glen Tarbert (S 10937). Only one slice has been examined of the small outcrops of appinite fringing the Strontian Pluton. It differs from slices of appinite south-east of Loch Linnhe in having two generations of hornblende (both are stumpy). The rock is probably ultrabasic, but includes as much granular quartz as felspar (oligoclase) in its base.

Ben Nevis (S 14046). Well crystallised quartz and microperthitic orthoclase are present in the base.

Binnein Beag (S 14082). The base consists of hypidiomorphic crystals of albite moulded about acicular tremolitic growths that proceed from the main hornblende crystals.

Eilean Balnagowan (S 7002). Some of the hornblende is brown. Perthitic orthoclase and quartz serve as base, with occasional micrographic intergrowth.

Ardsheal Hill (Walker 1927). Hornblende is greenish brown at the summit and brown further south. Anal. 1, Table 2, is an ultrabasic summit variety.

S.E. border, Ballachulish Pluton (S 11364, 11443-4). Hornblende is predominantly brown. Biotite fairly abundant ; and in (S 11364) augite too—a rare feature. Much of the felspar accompanying quartz is oligoclase.

Barnamuc Burn, Glen Creran (S 11359). Rare olivine pseudomorphs. Hornblendes bleached. A little biotite. Albite plates. Quartz and calcite in interspaces.

N.E. of Glenure House (S 11433-4). Felspar of base largely plagioclase.

Glen Chàrnan (S 8267). Approaching hornblendite.

Leacantuim, Glen Coe (S 11036-7). A beautiful rock (Pl. XI, 2). Hornblende greenish brown. Base of idiomorphic plagioclase surrounded by graphic intergrowths of quartz and orthoclase. Subordinate biotite. Acid segregation veins consist of a similar crystallisation of felspars and quartz with a few long needles of hornblende growing in from the sides.

Hornblende-Diorite Variant and Associates

Early Fault-Intrusion of Glen Coe.—Some of the Early Fault-Intrusion is basic, though some is intermediate or even acid (Anal. 19, Table 3). The more basic types range from diorite to porphyrite in crystallisation. Among these are hornblendic varieties which, as noted on p. 194, are extremely similar to the basic phase of the Beinn a' Bhuiridh Diorite at the south-east corner of the Etive Complex (Anal. 6, Table 2).

Let us start with two slices (S 9133, 13406) of this variety collected from the Coire an Easain outcrops (Fig. 29). They may be called basic hornblendic diorite with subsidiary augite and biotite—a basic development of the intermediate banatites. They are more felspathic than the appinites or biotite-augite-diorites so far described. Their felspar is acid labradorite with a strong tendency to stout idiomorphism and marginal zoning ; while their main ferromagnesian mineral is a rich brown hornblende. In one slice (S 9133) this hornblende builds crystals measuring over half a centimetre across and often moulded on the plagioclase ; whereas in the other (S 13406) hornblende crystals are smaller and tend to be elongated and idiomorphic. Augite, passing over to pale hornblende, and biotite are minor constituents ; and there is a little groundmass, which, in (S 13406) carries appreciable quartz. A slice (S 13404) from Sròn a' Choire Odhair-bhig (Fig. 24, p. 158) closely resembles (S 13406), but is definitely a porphyrite with lamprophyric tendency.

All the above are contact-altered, and three specimens of porphyrite (S 12358-12360) from Coire Mhorair (Fig. 24) show this feature very markedly. The first is cut across a junction with a granite to the west (mapped as "Granitite Fault-Intrusion" in Fig. 24) ; while the last is separated by a contemporaneous aplite vein from adjoining schist (not seen in slice). This last (S 12360) is probably intermediate, a definite banatite-porphyrite, as also another contact-altered specimen from Stob Mhic Mhartuin further east.

The analysed specimen (S 14109 ; Anal. 19) comes from the top of the ridge separating Coire Mhorair from Coire Odhar-mhòr (Fig. 24) and is far from typical of the Early Fault-Intrusion. It is a biotite-porphyrite carrying oligoclase phenocrysts in a ground consisting largely of alkali-felspar set in quartz; and its SiO_2 percentage of 65·30 places it in the acid category, though practically on the border line. In addition to normal oligoclase phenocrysts, there are some earlier felspars honeycombed as if by corrosion.

Finally we may note that the small patch of Early Fault-Intrusion at the bend of Càm Ghleann (p. 165 ; S 10328), though basic, is exceptional in that its hornblende is pale-green rather than rich brown. This pale-green hornblende is clearly developed after augite which is commonly preserved as irregular relics. The replacement looks like a result of juvenile reaction. There are several pseudomorphs with criss-cross pale-green hornblende which quite probably represent olivine. Otherwise in its development of stout idiomorphic basic plagioclase and accessory biotite the rock closely resembles the hornblende-diorites of Coire an Easain.

Intermediate, Acid and Ultra-Acid Plutonic Rocks

Main Fault-Intrusion of Glen Coe.—Much of the Main Fault-Intrusion (6 of Fig. 18, p. 129), like its Early predecessor, varies in texture from plutonic to hypabyssal. In addition, towards the north-west it is intensely xenolithic and extremely prone to permeate adjoining schists. In such case, though often carrying felspar phenocrysts, it develops an abnormal ground texture recalling somewhat that of a coarse aplite ; but much of its quartz is xenocrystal.

Both granitoid and porphyroid varieties may be grey or pink, while the permeating facies is pink. Pink varieties of all sorts are well developed, but not exclusively, in and about the An t-Sròn mass on the west, and also in the north (where they include a probably slightly later phase lettered G on Sheet 53).

Further east grey varieties are typically represented by the Fault-Porphyrite of Stob Mhic Mhartuin and the Fault-Tonalite of the Coupall River.

Whatever its general crystallisation, whether granitoid as at An t-Sròn or porphyroid as at Stob Mhic Mhartuin or permeative as in much of the intervening country, the Fault-Intrusion always chills against the Boundary-Fault of the Cauldron-Subsidence. If the intrusion is a normal porphyrite, as we have seen it is at Stob Mhic Mhartuin, it also chills against adjoining schist away from the fault ; *but not otherwise*.

We have already considered the relations between Fault-Intrusion and contemporaneous flinty crush-rock as revealed in slices from Stob Mhic Mhartuin (p. 162). Let us now see what has been learnt from specimens collected by Kynaston in the gorge eroded along the Boundary-Fault where it descends from An t-Sròn to Glen Coe (Fig. 20, p. 133)—one word of caution : a bedded ashy sediment, picked up in this gorge (S 10313, 10313a), must not be mistaken for flinty crush-rock.

A slice (S 10309) from near the fault illustrates the universal chilling in this position. It shows a red quartz-porphyry with phenocrysts of orthoclase, plagioclase, biotite and quartz (the last possibly derived) set in a felsitic groundmass. Its texture is definitely hypabyssal and contrasts strongly with the equally definitely plutonic crystallisation seen in the same intrusion (S 10308) a short distance further from the fault. The chilled slice (S 10309) cuts across a small pelitic xenolith, in one layer of which sillimanite and corundum occur. Felspar forming *lit par lit* laminae in this xenolith is more coarsely crystalline than groundmass felspar in the igneous host. It must have grown in the *lit par lit* position before the quenching of the host magma.

A neighbouring specimen (S 10310) furnishes a much better example of sillimanite-corundum-hornfels included in an igneous matrix which has been quenched to hornblende-biotite-porphyrite, a greyish type more basic than the porphyry just considered (S 10309). The hornblende phenocrysts here are pseudomorphed in criss-cross biotite indicating contact-action, presumably owing to continued intrusion of magma to build the An t-Sròn boss.

Still another slice (S 10311 ; Pl. XI, 4) is cut from a pelitic hornfels with a number of conspicuous pink felspathic *lit par lit* layers—a fine example of a migmatite. While much well-crystallised felspar has grown in the hornfels the pink layers consist largely of spherulitic felsite, sometimes with fully grown biotite phenocrysts. One sees here a *migmatite quenched while in course of development*. It is abundantly clear that the introduced igneous fraction entered as magma. One need scarcely point out that the chilling of the An t-Sròn margin as a whole witnesses equally clearly to the magmatic origin of this little boss of granite.

While in the An t-Sròn neighbourhood let us cross the Boundary-Fault a very short distance to look at the biggest of the very few, just three or four, little outcrops of Fault-Intrusion, which have managed to trespass into the Cauldron-Subsidence. It is lettered Gp on Sheet 53, and it is a grey porphyrite (S 11904), with abundant stout plagioclase phenocrysts up to about 4 mm long. These are more broken perhaps than usual ; but otherwise the rock as a whole is closely similar to the Stob Mhic Mhartuin porphyrite, described below. Maufe collected from it a lava xenolith, originally augite-andesite or basalt, about 6 cm long and surrounded by a coat, one or two centimetres thick, of pink, highly quartzose rock, to be spoken of below as the " pink rock "—this is the " Fault-Intrusion loaded with clear xenocrysts of quartz " of Pl. XI, 6. The lava of the xenolith is seen under the microscope to be completely reconstructed into a very fine-grained hornblende-felspar-schist or schistose granulite. Greenish-brown biotite is usually a subordinate constituent, but may altogether take the place of hornblende towards the margins of the xenolith. Minute grains of magnetite are fairly common. The hornblende is pale-green and builds little prisms, rarely 0·1 mm long ; while the biotite makes correspondingly small flakes. The schistosity is expressed in the orientation of these two minerals, but is not pronounced. Former phenocrysts of ferromagnesian minerals are now represented by oval groups of criss-cross hornblende. There is considerable resemblance between this hornblende-schist, with subordinate biotite, developed on a very small scale at Glen Coe from basic andesite or basalt lava, and the well-known biotite-schist, with subordinate hornblende, developed on a fairly large scale in the Beinn a' Bhuiridh screen from hornblende-andesite lava—this last was elucidated by Kynaston and more fully by Anderson (S 7627-8, 8258-8260, 9312, 9316 ; Kynaston *in* Hill, Kynaston and others, 1908, p. 96 ; Anderson 1937a, p. 517).

The Glen Coe xenolith is crossed or margined by a number of shear planes running in different directions ; in fact its boundaries have been in large measure determined by resultant planes of weakness. The oldest crush-line that is seen in a junction slice (S 11905a) is filled with 1 mm of flinty crush-rock or something closely allied. This contains much-broken felspar along with a few bigger grains of quartz. The felspar has come in large measure from a recrystallised fringe of the biotite-facies of the xenolith. The quartz grains are forerunners of the " pink rock " ; but most of this latter came somewhat later on the scene and swept across the film of crush-rock just described. It is probable that the time-interval was trivial. Both the early crush-seam and the later surrounding " pink rock " were responsible for developing marginal biotite in the xenolith.

Some of the border crushing of the xenolith has manifestly affected adjacent " pink rock ". As a rule in such case the xenolith is still fringed, at contact, with biotite-facies, though the biotite may share in the crushing. Probably in such a case the movement was small and carried through while the " pink rock " was quite hot. Locally a crush-junction of xenolith and " pink rock " finds broken hornblende right up to the contact ; and where this is observed it is likely that biotite-facies has been faulted out. Locally too there may be chloritic replacement of hornblende in a crush-zone, probably due to comparatively late, low-temperature adjustment.

The "pink rock" consists to about half its volume of roughly rounded grains of quartz, measuring up to a millimetre across ; and it closely resembles the Fault-Intrusion, where this latter, north of Glen Coe, assumes an arkosic appearance through admixture with disintegrated quartzite (pp. 157, 219 and Pl. XI, 5). Only, in the present instance, the quartz grains are held in a microfelsitic matrix, *very much finer than what is seen north of Glen Coe well outside the Boundary-Fault.* This is important. We examine here (S 11905) a quenched representative of permeated, mobilised quartzite, which probably no one would claim as a product of crystallisation from ultra-acid magma. It is inconceivable that such a magma could crystallise so large a proportion of its quartz in 1 mm grains before it started to crystallise any of its felspar.

The junction of the thin layer of " pink rock " with the surrounding intermediate grey porphyrite that constitutes almost all the little invasion of Fault-Intrusion is highly irregular. When the two met, their matrixes were liquid and mixed in complex fashion. Still one can see that the crystallisation of the " pink rock " matrix is just a shade more apparent than that of the adjacent grey porphyrite. This difference does not mean that the " pink rock " matrix was the hotter of the two, but merely that it was more acid, and therefore more crystallisable when dropping to the low temperature it found within the Cauldron-Subsidence. Actually the grey porphyrite matrix was the hotter of the two, for comparison of slices (S 11905 with S 11904) shows that the phenocrysts of the grey rock are smaller, and that the groundmass is appreciably finer, at contact with the " pink rock " than at a little distance. Another interesting feature is that hornblende xenocrysts supplied to the " pink rock " from the grey show two successive types of alteration. They usually carry a narrow rim of criss-cross biotite surrounding interiors replaced by the same kind of chlorite as has been noted as a late-stage product in crushes crossing the xenolith.

To sum up :—The xenolith of basic andesite or basalt lava travelled a short distance into the Cauldron-Subsidence from the immediate proximity of the Boundary-Fault. While in the fault-zone it had been subjected to successive crushing, and involved in an uprise on a small scale of " pink rock " magma—which latter in depth had become charged with quartz xenocrysts through interaction with Glen Coe Quartzite. After that, along with some adherent " pink rock " magma, the xenolith was carried into its present position by intermediate grey Fault-Intrusion magma ; and there it and its associates were quenched in the cold environment of the Cauldron-Subsidence.

Before proceeding further in regard to permeation (p. 219), let us note a few more details about apparently uncontaminated varieties of the Main Fault-Intrusion.

The analysed rock (S 12351, 14117, Anal. 12, Table 2) from Stob Mhic Mhartuin furnishes an excellent example of the grey, intermediate, porphyrite type, and may be classed as banatite-porphyrite. Under the microscope it proves to be surprisingly like much of the Early Fault-Intrusion. One says " surprisingly," for the two intrusions can be easily distinguished in the field—though this follows largely from disturbance and baking affecting the earlier. There are the same rather basic felspar phenocrysts, labradorite or andesine, and the same rich-brown phenocrysts of hornblende and biotite (here marginally resorbed as in a lava). Idiomorphic pyroxenes, both monoclinic and rhombic, make fairly frequent small phenocrysts. Magnetite is also an early mineral ; while the felspathic groundmass carries but little quartz. Apatite is a fairly abundant accessory.

A more acid, pink porphyrite (S 12350) from Meall Dearg is very similar, but with less pyroxene among the phenocrysts, and more quartz and alkali-felspar in the groundmass.

In another specimen (S 12495),a grey, intermediate rock from the River Coupall, the phenocrysts have grown so large at expense of the groundmass that the rock is of plutonic aspect. Its pyroxene is less abundant than at Stob Mhic Mhartuin, and tonalite or tonalite-porphyrite seems the appropriate name. Tonalite also fits three other slices (S 9129, 12502-3) from the rivers Etive and Coupall, in which hornblende is paler and greenish, while pyroxene is almost wanting. Their crystallisation is plutonic. They carry very little orthoclase or quartz. The idiomorphic tendency of their stout plagioclase felspars connects them texturally with the coarse porphyrite facies.

Another related grey coarse porphyrite merging into tonalite (S 10305) is represented from the east side of the An t-Sròn boss ; while grey quartz-biotite-diorite (S 10307) from the River Coe in the same neighbourhood differs mainly through the absence of hornblende.

Pink adamellites (S 10308, 10306) may be quoted from An t-Sròn and the opposite slope across the Coe. They contain a little biotite and a considerable proportion of quartz and orthoclase. It is always open to question how far the acid products of the Fault-Intrusion have been acidified through reaction with quartzite such as is described below.

In the Glen Etive region the Fault-Porphyrite (S 11503-5, 11576) has suffered contact-alteration by the Cruachan " Granite ".

The " Granitite Fault-Intrusion " partly included in Fig. 24 (p. 158) is an adamellite with little hornblende, but well developed biotite, oligoclase, orthoclase and quartz (S 12349, 12352—the latter with contemporaneous aplite). The texture is allotriomorphic though with oligoclase elongated. A probably related vein in schist that is shown as phyllite in the N.W. corner of Fig. 24 is almost a binary granite (S 12353) with quartz in equidimensional grains upon which large crystals of cryptoperthitic orthoclase are moulded. A neighbouring little boss is even more acid (S 13343) and very prone to graphic intergrowth. All three types can be matched fairly closely in the acid facies of the Cruachan " Granite " (see below), though the vein (S 12353) also suggests slightly the permeation products of the Fault-Intrusion of the following paragraph, of which possibly it may be an extreme modification. The granitite, or adamellite, mass makes a narrow merging contact (S 13342) with the Fault-Intrusion, in which age relations are not clear.

We are now in a position to consider more closely the permeation phenomena connected with the Fault-Intrusion, especially in the northern area between Garbh Bheinn and Glen Coe (p. 157). Several slices (S 11517-11522, 12354-7) have been examined from an extensive intrusion-breccia on the flanks of Garbh Bheinn. This is mapped on Sheet 53 as Fault-Porphyrite, and is exposed in a tributary that joins Allt Gleann a' Chaolais from the north-east rather more than a mile above Caolasnacon. The intrusion-breccia carries innumerable xenoliths derived from adjoining mica-schist and quartzite ; and both xenoliths and country-rock show much contact-alteration including felspathisation.

The xenoliths lie at all angles, and where pelitic have generally developed numerous small flakes of intensely pleochroic biotite, occasionally accompanied by larger poikiloblastic crystals of the same. The small flakes may be distributed with marginal concentration (S 11518, 12354). Other almost constant features are little crystals of magnetite along with quartz and felspar. Andalusite may be common (S 12355) ; shimmer aggregate abounds ; pinite, clearly after cordierite, is sometimes seen (S 11518) ; corundum also, occurring in small crystals (S 11519, 11520). *Lit par lit* injection is well exhibited in certain hand specimens (S 11520, 11522).

It is to the enclosing matrix that attention is here specially directed. This may be of normal igneous appearance : for instance it may be coarse porphyrite with phenocrysts of oligoclase, orthoclase and biotite in a well crystallised groundmass of quartz graphically intergrown with alkali-felspar (S 11519) ; or, with practically no phenocrysts, it may be coarse felsite or fine binary granite (S 11520) ; or again it may be acid adamellite, with subdued porphyritic tendency, and on the whole of allotriomorphic texture (S 12357). The quartz in such cases occurs in grains, often in contact and usually measuring less than 1 mm across.

On the other hand, in most specimens in the Survey collection, the matrix, whether it carries fairly numerous felspar phenocrysts (S 11518, 12354), or no (S 11517, 11522, 12355-6), is definitely abnormal, for it is crowded with sub-rounded quartzes with irregular margins moulded upon smaller intervening crystals of alkali-felspar. A common size for the quartz grains is about 1 mm, and for the felspars 0·1 mm. In hand specimens the quartz grains give the containing rock a definitely arkosic appearance, as may be realised from Pl. XI, 5 (p. 211).

The quartz grains in these abnormal rocks closely resemble, as noted already, the quartz grains of the quenched " pink rock " south of Glen Coe (p. 217 ; Pl. XI, 6). They differ, however, in their marginal moulding upon intervening felspar crystals, for in the quenched " pink rock " such intervening crystals have not developed. They also recall abundant minute quartz grains seen in an aplite vein (S 12515) cutting Cruachan " granite " ; but the quartzes of this aplite are much smaller, and what is probably significant, are of the same general size as the accompanying felspars. Putting all this evidence together we may say :

(1) In the quenched " pink rock " the quartz grains were present before the felspar crystallisation started—this is straight-forward observation.

(2) In the unquenched permeation zone the quartz grains, to judge from their size, were in the main earlier than the felspar crystallisation, though they added marginally to their substance even after felspar crystallisation had almost ceased.

(3) In the aplite the crystallisation of quartz and felspar seems to have been essentially simultaneous.

Slices (S 11517, 11517a) from the present locality show the edge of a quartzite xenolith from which quartz grains, exactly similar to those that are widespread in the intrusion-breccia matrix, are being prised off through intergranular entry of alkali-felspar (Pl XI, 5). It appears certain from what is seen in the field and under the microscope that a great quantity of quartzite has thus been subdivided into isolated xenocrysts (subsequently modified), while associated mica-schist has preferentially given xenoliths—there are also plenty of xenoliths of quartzite, some of which, according to Hardie (1955), are gigantic. We may recall that Teall (1899, p. 642), following Horne, long ago described a granite contact in the Southern Uplands, at which " coarse-grained quartz rock," resulting from thermal crystallisation of radiolarian chert, " becomes more or less disintegrated," so that " detached grains . . . . may be isolated in the igneous matrix " (S 4953-4969). His evidence, like that conveyed in (S 11517) quoted above, is completely convincing ; but it might be discounted as concerning only a small-scale phenomenon. In the Glen Coe area we seem to have evidence of grain by grain subterranean erosion of quartzite by magma on a large scale. The process may be styled, by those who like long words, dispersive permeation accompanied by mobilisation. It is probable that important volumes of quartzite were thus tranferred to upper regions, perhaps to the surface.

Etive Complex.—The following brief account of the rocks of the Etive Complex (8 of Fig. 18, p. 129, excluding 6, the Fault-Intrusion of Glen Coe) must be read in conjunction with chapter xiii, where a full statement of subdivisions and field relations will be found. As there mentioned, Anderson's description (1937a) should be consulted for further detail.

The *southern lobe of the Cruachan " Granite "* is only represented in the Geological Survey collection from Sheet 53 by a contact specimen (S 15877) ; but its low-level grey facies is like a sliced rock (S 7758) from Sheet 45, Geol. This is a tonalite with biotite more abundant than green hornblende, much oligoclase, a fair proportion of quartz and extremely little orthoclase. Anderson describes upward merge into acid types, such as is outlined below for the northern lobe. In the southern lobe he finds the average specific gravity to be 2·73 below 2000 ft and 2·67 above (1937a, p. 516). He raises a further interesting point in recording contact-alteration of the Cruachan " Granite " at three-quarters of a mile from the Starav Granite, and apparent absence of change at close quarters.

The *northern lobe of the Cruachan " Granite "* is everywhere pink and acid. The characteristic type at low levels (S 11559, 11562, 12513-5, 14112, 14176) is a hornblende-biotite adamellite, with green hornblende, brown highly pleochroic biotite, and a good development of oligoclase-andesine, or oligoclase, and cryptoperthitic orthoclase. Sphene and apatite are accessories, the former often conspicuous. As a rule the oligoclase gives the biggest and best-formed crystals, which sometimes function as vague phenocrysts. A slice (S 14112) from the analysed specimen (Anal. 26, Table 3) shows a patchy development of its more basic minerals ; and some of its hornblende crystals include relics of augite. In another (S 11562) there is an approach to the still more acid types of high levels ; and microcline twinning is fairly frequent, an unusual feature for Sheet 53. Two slices (S 11561, 12515) have been cut to illustrate acid veins. The former shows throughout fine graphic intergrowth of quartz and alkali-felspar, occasionally twinned on the microcline pattern. The latter (S 12515) has only a 2-mm graphic fringe, and is mainly an aplite with minute subrounded grains of quartz and alkali-felspar, of roughly equal size.

The upward passage of the Cruachan " Granite " of the northern lobe, from adamellite at low levels into binary granite at higher, has been vouched for by Kynaston, Grabham and J. G. C. Anderson. Two slices (S 11533, 11543) collected by Grabham represent middle levels and compositions. They show highly quartzo-felspathic granites, with biotite as the ferromagnesian mineral and with crypto- or micro-perthitic orthoclase preponderant over oligoclase.

The summit type, represented by Grabham's specimens (S 11534, 11542, 11552-3, 11569-70) comes very close to binary granite through further reduction of biotite and oligoclase. In fact the term binary granite or near-binary granite conveys the essentially quartz-orthoclase composition much better than plain granite. The texture varies, and in three of the slices (S 11542, 11553, 11570) there is some graphic intergrowth. Local abundance of drusy cavities is noted in the field description. The composition must often be ultra-acid.

The pink *Meall Odhar Granite* of the Etive Complex (S 11497-9) is in its type locality a coarse binary granite with a little oligoclase and biotite, this latter sometimes altered to chlorite. By far its most abundant felspar is more or less perthitic orthoclase. The texture tends in part to be graphic. The rock very locally (S 11498) has suffered from granulitisation along shear planes developed probably at a fairly high temperature.

The only known difference between the Meall Odhar Granite and the hill-top facies of the Cruachan " Granite," noted above, is that the former is definitely the younger of the two (see chap. xiii). What Anderson, with good justification, takes to be Meall Odhar Granite at Stob Gaibhre, south of Glen Ure, is again of similar type, but is not represented in the Survey collection. Its southern continuation is represented in Anal. 31, Table 3.

The *Starav Granite* of the Etive Complex is later than the Meall Odhar Granite (chap. xiii). Most of what enters Sheet 53 belongs to the porphyritic margin of this boss, here half a mile wide and merging very gradually into non-porphyritic interior, which latter is mostly included in Sheet 45 (Geol.) to the south. The porphyritic facies (S 7752) is represented from Glen Kinglass in Sheet 45. In the available slice a big pink felspar, 2 cm long and 1 cm broad, is partially shown. It is one that helps to give a porphyritic appearance to the rock ; but even with no more than a pocket lens it is seen to be completely allotriomorphic. We shall find presently at Ben Nevis that such crystals have resulted from continuous outgrowth of phenocrysts. The specially big pink felspar in the slice (S 7752) is perthitic orthoclase. It includes among others oligoclase crystals, which are fairly idiomorphic but not of outstanding size. Kynaston, however, noted that the large phenocrysts of the porphyritic zone in general are both pink and white ; and examination of hand specimens shows that the latter are clearly plagioclase with twinning stripes. It is quite common among hypabyssal porphyrites to find both orthoclase and plagioclase occurring together as phenocrysts.

The Glen Kinglass rock (S 7752) has more than twice as much orthoclase as plagioclase. It can be classed as a biotite-granite allied to adamellite. It is rich in quartz, but its fairly abundant hornblende and biotite as well as its felspar phenocrysts distinguish it from the hill-top binary facies of the Cruachan " Granite ". Accessory sphene is less conspicuous than in the adamellite facies of the latter found lower down.

The analysed specimen (Anal. 29, Table 3 ; S 14111) is from the transition zone between porphyritic and non-porphyritic. It differs from the Glen Kinglass rock (S 7752) in having rather smaller allotriomorphic crystals of microperthitic orthoclase ; but otherwise it is so similar as not to require separate description.

The fully developed non-porphyritic interior contains less ferromagnesian constituents, but is not represented among Geological Survey slices from Sheet 53.

Ben Nevis Complex.—Chapter xiv has been devoted to the field relations of the Ben Nevis Complex (1 of Fig. 18, p. 129). These were elucidated by Maufe, except for the subdivision of the usually grey, non-porphyritic portion of the Outer " Granite ". Here we are indebted to J. G. C. Anderson (1935b), whose work on the petrology of the resulting subzones, 1 fine, 2 medium and 3 coarse-grained is summarised below.

Subzone 1 of the Outer " Granite " of Ben Nevis (Fig. 31, p. 178) is a fine-grained rock, usually a grey quartz-diorite of Banat type—what we call in this memoir a banatite. Its ferromagnesian minerals are augite, biotite and hornblende ; while its felspar is mainly oligoclase, and interstitial quartz is abundant. Analysis 11, Table 2 is representative. Low-level outcrops on the west and north have specific gravity averaging 2·73, and are more basic than high-level outcrops on the east, where a specimen gave 2·64.

The only slice (S 8817) in the Geological Survey collection comes from Allt na Caillich (Fig. 31) near the schists on the west, and seems exceptional. Its augite mostly occurs as scant relics in plentiful hornblendes, but it also builds a few small independent crystals. Its biotite is abundant ; and so is its orthoclase, in large poikilitic crystals enclosing oligoclase, etc. Hill and Kynaston have drawn attention to its monzonitic affinities (1900, p. 540). The plagioclase crystals often show needly clouding suggestive of contact-alteration.

Subzone 2 of the Outer " Granite " of Ben Nevis (Fig. 31) is medium-grained, and is usually a grey banatite (Anal. 15, Table 2), though at high levels in the east it becomes a biotite-granite. Average specific gravity at low levels in the west and north is 2·75, and at high levels in the east 2·65.

Subzone 3 of the Outer " Granite " of Ben Nevis (Fig. 31) is the innermost and latest of the three outer, non-porphyritic subzones ; and it makes a merging contact with the porphyritic Subzone 4 next to be described. It is the coarsest of the three non-porphyritic subzones, and in the lower ground of the west and north, away from its contact with Subzone 4, the main type is once more banatite (Anal. 8, Table 2), with fairly abundant hypersthene and augite, hornblende (frequently rimming augite), late-crystallised biotite, andesine or oligoclase and a little orthoclase and quartz. A slice (S 8816) from the tributary which enters Glen Nevis just south of Claggan farm seems abnormal in that much of its pyroxene is replaced by irregular sheaves of pale hornblende suggesting contact-alteration rather than normal auto-reaction. The plagioclase also shows faint needle clouding. Possibly the specimen has been taken from an enclosure belonging primarily to Subzone 2.

The banatite of Subzone 3 passes into adamellite as we ascend to the high exposures on the east side of the complex. Anderson found an average specific gravity of 2·79 on the west and 2·69 on the east. " It is interesting to note," he remarks (1935b, p. 343), " that the difference of height between the highest exposure of the Coarse Type [Subzone 3], that on Aonach Mòr, and the lowest, that in the River Nevis, is over 3900 feet, the greatest exposed vertical thickness of any igneous intrusion in the British Isles ".

The banatite of Subzone 3 also passes into adamellite in the transition belt connecting it with the porphyritic Subzone 4, the innermost subdivision of the Outer " Granite ". A specimen taken from this transition belt at about the 800-ft level on the tourist path to the summit is in hand-specimen (S 14420) a pinkish granitic-looking rock with inconspicuous porphyritic texture. Under the microscope, pyroxene is wanting, while hornblende, biotite, oligoclase, cryptoperthitic orthoclase and quartz, all build big, rather ill-formed crystals, which can be termed phenocrysts, set in a coarse granular matrix of quartz and alkali-felspar. Sphene and iron ore are the main accessories. This rock is better described as an adamellite-porphyrite or porphyry rather than plain adamellite. Some of its plagioclase shows very faint needle clouding.

Subzone 4 of the Outer " Granite " of Ben Nevis (Fig. 31) is thorough biotite-hornblende-granite (Anal. 21, Table 3) with more than twice as much cryptoperthitic or microperthitic orthoclase as plagioclase (S 8814). This orthoclase makes conspicuous pink patches, sometimes 2 cm long, which evidently, from analogy with what is seen in (S 14420), just described, should be interpreted as outgrown phenocrysts. Under the microscope the phenocrystal appearance is lost owing to the allotriomorphic outgrowth. Quartz is abundant and builds big crystals and groups of crystals in much the same manner as the orthoclase; but it does not achieve a phenocrystal appearance. Zoned plagioclase, near oligoclase, biotite and hornblende are more idiomorphic. Sphene continues an accessory.

The *Inner " Granite " of Ben Nevis* (Anals. 24, 28, 30, Table 3) has already been discussed as in large measure a trondhjemite. It is in general a pale pinkish rock, of fine-grained granitoid appearance, and with very subdued porphyritic tendencies. Maufe has collected several interesting specimens. Two from Allt a' Mhuilinn, (S 8815) a little upstream from the Porphyritic Subzone 4 of the Outer " Granite " and (S 14421) approaching the downfaulted andesites, are both essentially made of biotite, plagioclase, orthoclase and quartz. The plagioclase is roughly twice as abundant as the orthoclase ; and its stumpy crystals, rarely 3 mm long, are highly zoned. They may start with labradorite and end up fringed with clear primary albite.

An actual junction (S 14043) between Inner and Outer " Granites " from Allt a' Mhuilinn shows a closely similar, but rather more alkali adamellite facies of the Inner " Granite," which is characterised by oligoclase and abundant orthoclase. As seen in all exposures of this contact, the Inner " Granite " exhibits no sign of chilling. Also the slice reveals no contact-alteration of the

Outer " Granite," though, it will be remembered, an important phase of dyke intrusion separates the two " granites " in time. Maufe has collected two specimens from one of the dykes above Allt Daim mentioned on p. 182. The dyke is a microdiorite ; in the first specimen (S 14047) we see its fine-grained edge (granulitised by subsequent recrystallisation) cutting typical Outer " Granite " ; while in the second (S 14048) its coarser interior is crossed by the Inner " Granite ". The hand-specimens tell the complicated story much more clearly than the micro-slices. Then from Allt Coire Gaimhnean, on the other side of the complex, Maufe's collection shows a baked dyke (S 14049) with close beside it later trondhjemitic Inner " Granite " (S 14050, p. 182). The dyke is thoroughly crystallised with more graphic intergrowth than usual.

The contact of Inner " Granite " with the cold down-thrown volcanics of the cauldron-subsidence is very strikingly different : a specimen (S 14044), collected by Maufe from Coire Eoghainn 600 yd S.S.W. of Ben Nevis summit, shows that the " granite " has passed into a fluxion rhyolite with 2-mm phenocrysts of oligoclase and 1-mm phenocrysts of biotite ; and that this rhyolitic margin is separated from andesite lava by 1·5 mm of flinty crush-rock—indistinguishable from the andesite in hand specimen. The andesite is slightly baked with development of exceedingly small flakes of biotite.

The flinty crush-rock in this specimen (S 14044) is recognisable under the microscope on comparison with Glen Coe analogues (p. 161). It appears as a microscopic to ultra-microscopic breccia with recognisable debris derived from both andesite and rhyolite. The marginal fluxion of the rhyolite is wavy, and its drag involves the adjacent crush-rock ; while its phenocrysts, where they touch the latter, bend or break. Presumably the flinty crush-rock has been brought down from a higher level where it formed along the Boundary-Fault of the Ben Nevis Cauldron-Subsidence, up which Inner " Granite " magma was just starting to ascend.

Another specimen, from Allt a' Mhuilinn (S 14045), shows that the flinty crush-rock may be fully 4 cm thick in places. Again debris from both the marginal Inner-" Granite "-rhyolite and the andesite lavas is recognisable.

Mullach nan Coirean and Meall a' Chaoruinn Granites.—The granite of the twin outcrops (2 of Fig. 18, p. 129) of Mullach nan Coirean (S 8487) and Meall a' Chaoruinn (S 8276) affords an almost ideal example of a binary granite. In the hand it appears as a well crystallised pink to red granite, with quartz showing a tendency to a blue tint. Muscovite may here and there be seen.

Under the microscope quartz sometimes shows crystal faces ; and very occasionally it joins the orthoclase in pegmatitic growths. The great bulk of the felspar is microperthitic orthoclase, but albite and oligoclase and also microcline are represented. Biotite and magnetite constitute very minor accessories. The rock is probably often ultra-acid.

Loch Linnhe Granites.—The red granites following the north-west shore of Loch Linnhe (*e.g.* 3 of Fig. 18, p. 129) have not been microscopically studied, so that we cannot add here to what has been said of them in chapter xv.

Strontian Complex.—The Strontian Complex (4 of Fig. 18, p. 129) scarcely enters Sheet 53. Chapter xv has supplied a brief summary of a paper on the complex by MacGregor and Kennedy (1932), and a fuller account is being prepared for the forthcoming Geological Survey memoir on Sheet 52 (Geol.). Slices cut from Sheet 53 exposures are (S 10930-2, 10935-7, 11029-30, 11032-5). They come in large measure from a fringe of small intrusions extending a little outside the boundary of the coherent complex.

Ballachulish Complex.—The Ballachulish " Granite " Complex (5 of Fig. 18, p. 129) has been separated in chapter xv, following Lawrie, into a grey, more or less outer, early tonalite and a pink, more or less inner, later granite. There is also at Rudh' a' Bhaid Bheithe a local marginal strip of " white granite " described by Walker.

The strip of " *white granite* " (Anal. 27, Table 3) has been dealt with sufficiently in regard to its sulphur content in chapter xv, and has been mentioned again in relation to the use of the name trondhjemite. Similar rock (S 11363) on the other side of the main pluton makes a small isolated " granitic " boss in Allt Eilidh.

The well known *grey tonalite* (Anals. 10, 13, Table 2) resembles the main Fault-Intrusion of Glen Coe in carrying a multitude of xenoliths. It is of very even, medium-grained texture (S 7052), and consists of comparatively idiomorphic brown biotite, green hornblende and andesine, in a subordinate matrix of allotriomorphic quartz and cryptoperthitic orthoclase. The last-named occurs in rather large poikilitic crystals. Sphene, apatite, magnetite and zircon are accessory. The sphene, as Teall has pointed out, is moulded on the plagioclase and ferromagnesian constituents.

The later *pink granite* is shown by Anals. 20, 25 of Table 3 to include varieties with much the same compositions as the unusually acid Early Fault-Intrusion (Anal. 19) and the Cruachan adamellite (Anal. 26).

Rannoch " Granite ".—The western margin of the Moor of Rannoch " Granite " (7 of Fig. 18, p. 129) enters Sheet 53 between the Blackwater Reservoir and Càm Ghleann ; and a short description is given in chapter xv. The next two paragraphs are based on specimens collected from a little way into Sheet 54 (Geol.) in the neighbourhood of Kingshouse Hotel.

Specimen (S 9128) was taken by Kynaston to represent the main grey, slightly foliated type with conspicuous alined blebs of quartz. It is an unusually quartzose tonalite with abundant green hornblende, brown biotite and oligoclase. A little microperthitic orthoclase occurs in rather large allotriomorphic crystals, sometimes invaded by myrmekite. Sphene is a conspicuous accessory. Another specimen (S 12794) selected by Grabham, also as typical, is very similar, though the slice includes so much quartz that the rock should probably be classed as a trondhjemite rather than a tonalite.

Incoming of additional orthoclase as the margin of the intrusion is approached is seen in a specimen (S 12793) collected by Grabham to illustrate this feature. It is also shown in the analysed rock (S 14110, Anal. 23, Table 3). In this last biotite predominates over hornblende, but oligoclase remains more than twice as abundant as orthoclase. The analyses shows that the rock is acid, and as an acid granodiorite it is here classed as trondhjemite.

Sheet 53 affords excellent examples (S 11528, 12749-50, 14080) of the thoroughly acid pink, slightly porphyritic marginal facies. They come from the dam site of the Blackwater Reservoir and from the Rivers Coupall and Etive. They are thoroughly acid, coarse, biotite-granites in which orthoclase generally strongly predominates over plagioclase. There has been so much outgrowth from early phenocrysts that the ill-marked porphyritic texture seen in hand specimens practically disappears under the microscope.

" Granite " Boulders in Lower Old Red Sandstone Conglomerates.—The " granite " boulders from various conglomerates of Glen Coe are fairly decomposed, with biotite their only ferromagnesian as yet found fresh. Pseudomorphs that are probably after hornblende occur in certain cases. Alkali-felspar is cryptoperthitic orthoclase as in the local plutonic assemblages. This orthoclase is sparingly developed, so that most of the boulders are tonalite or quartz-biotite-diorite (S 10285-8, 10326, 12334-5, 12788-9). The last two specimens cited come from Càm Ghleann, and have been justifiably compared by Grabham with the marginal facies of the Moor of Rannoch " Granite " close at hand (p. 147). The reader may be reminded that the plutonic types found in the conglomerates are far outnumbered by lava types such as make up the volcanic pile of Glen Coe. Hypabyssal types are rare, though quartz-porphyry has been collected (S 10289).

A similar suite of granitic boulders (S 10295-6, 10299, 18692, 18694) has been found near Oban in the Lower Old Red Sandstone conglomerates of Lorne (Sheets 44, 45, Geol.). Here too there is an occasional quartz-porphyry, (S 18693) ; while granophyre is another rarity (S 10297). The latest account (Bailey 1925, p. 26) follows Kynaston in assigning these boulders, both in Lorne and Glen Coe, to " granites " of the Lower Old Red Sandstone suite, brought to the surface by explosion or possibly sometimes by erosion (*cf.* p. 131).

BASIC HYPABYSSAL ROCKS

Lamprophyre : Introduction.—The rocks here considered are dark, medium- to fine-grained lamprophyres rich in ferromagnesian minerals that are generally hornblende though sometimes with a considerable proportion of biotite, augite and olivine. The ferromagnesian minerals, apart from the biotite, are idiomorphic. The biotite usually occurs in small hypidiomorphic flakes. The felspar often builds big groundmass crystals ; but more basic plagioclases may occur as laths, in which case the general texture is panidiomorphic. Apatite is an abundant accessory, and, in keeping with this, juvenile reaction is frequent, producing green biotite, colourless amphibole, albite, calcite and occasional epidote. It will be pointed out (p. 259) that such juvenile alteration is often very difficult to distinguish from subsequent contact-alteration.

Three species of lamprophyre are represented in the district, namely hornblendic spessartites and vogesites and biotitic kersantites. The spessartites and vogesites should be distinguishable from one another by predominance of plagioclase in the base of the former and of orthoclase in that of the latter ; but as the plagioclase is often alkaline, little-twinned and turbid the difference may be impossible to establish in detail. Taken together the spessartites and vogesites of the district correspond in every respect, except for their finer texture and an absence or rarity of micropegmatite, with the appinites described above.

In 1902 Flett showed that most of the rocks previously styled camptonites on the mainland of Scotland should be transferred to the spessartite group (Sum. Prog. 1902, p. 69). In this he was confirmed by Rosenbusch (1907, p. 170), who regarded the camptonites and spessartites as belonging to the essexite and diorite families respectively. The camptonites tend to have purple augite, deep-brown (basaltic) hornblende and late analcite ; whereas in spessartites augite is pale-green to colourless, hornblende is pale-brown often greenish, and analcite is absent.

Kersantites may be defined as biotite-lamprophyres with plagioclase as their felspar. They are sparingly represented in Sheet 53 ; and it is very seldom that anything is found that might be called a mica-trap.

Early Lamprophyre Sheets.—The widely distributed, early, low-angled lamprophyre sheets of chapter xvi almost all belong to the spessartite suite ; and more typical lamprophyres could not be desired. Their felspar furnishes an allotriomorphic, poikilitic base, and consists largely of oligoclase or albite. Prisms of hornblende may supply almost all their ferromagnesian component, stout (S 11527, 12888-9, 15876), or needly (S 12888a, 12890). The sheet represented by (S 15876) is a conspicuous feature in the main Ballachulish slate quarry, but is very decomposed. There may be in addition big phenocrysts of augite largely made over to pale-green hornblende (S 11495). A slice (S 12348) from Allt a' Choire Odhair-mhòir suggests that a plutonic rock consisting of richly sagenitic biotite, colourless augite and brown hornblende may have been dismembered by an invasion of what seems to have been felspathic magma. In others, calcite (S 11527, 12888), green biotite (S 12888, 12888a), tremolite (S 11527), epidote (S 12889) and chlorite (S 12890) are well represented.

Lamprophyre Dykes : Etive Swarm and Older Associates.—Two lamprophyre dykes (S 11523-4) from the permeation zone north of Glen Coe have been contact-altered by the Fault-Intrusion, and are therefore earlier than the Etive Swarm. They will be referred to more fully in chapter xviii. Even if all other lamprophyre dykes within the belt traversed by the Etive Swarm belong properly to that swarm, there are very few compared with the prevailing porphyrites ; also, as pointed out on p. 195 some of them may quite likely antedate the swarm.

Among the suspects is a hornblende-spessartite that has located the E. N. E. gorge along which the Coe flows 400 yd S.W. of Clachaig Hotel. Petrographically it is just like the spessartites of the early sheets. An additional feature of interest is its intrusion by very irregular felsitic material, probably penecontemporaneous (S 11612, 39702-5). A dyke of like character (S 11040) on the northern slopes of Glen Coe may be a continuation. Maufe noted that it was cut by a number of porphyrite associates. Another dyke seven miles further south-east at Sròn na Creise is similar (S 9738) ; as are also others (S 12480, 12517, 11571, 12893, 12895, 13763) from various localities.

It would, however, be unsafe to assume that all the above are earlier than the Etive Swarm. Thus very much the same type of spessartite reappears in a patchy dyke (S 12943-6) which certainly belongs to the swarm, since it cuts the Fault-Intrusion of Glen Coe. It gives rise to a gorge on the south-west side of Stob Beinn a' Chrùlaiste near the east margin of the map, where it is lettered L. It approaches specially closely in type such of the early sheets as carry augite and biotite. It differs mainly through a tendency of the felspar to be idiomorphic with a little intervening micropegmatite. The augite too is often rimmed with hornblende.

A rather finer-grained dyke (S 14106), further west, is an olivine-augite-hornblende-spessartite, differing from the early sheets in having less hornblende and in the lath-shaped habit of its plagioclase. Slices (S 11550, 11582) are comparable, while (S 11475, 11526) carry sufficient biotite to approach kersantite. This feature is accentuated in a fine-grained kersantite (S 12338) cutting Fault-Intrusion.

Three other kersantite slices of a different type come from the Binnein Mòr—Binnein Beag area north-east of Kinlochleven : (S 12891) was collected by Wright as a dyke ; (S 12896) as a dyke or sheet ; and (S 12897) as a sheet. They are with some hesitation referred to the Etive Swarm. Biotite is abundant in parallel flakes, often more than half a millimetre long. Olivine is represented in bigger, and augite in smaller pseudomorphs. All minerals except biotite and magnetite are decomposed.

Lamprophyre Dykes : Ben Nevis Swarm.—Lamprophyres are also scarce in the Ben Nevis Swarm ; spessartites are represented by four slices (S 6559, 8488, 8822, 14427). Of these (S 6559) is of the same type as the early sheets, while the three others have lath-shaped felspars : (S 8488) cuts Mullach nan Coirean Granite, while (S 8822, 14427) cut the Outer " Granite " of Ben Nevis and seem to have suffered a little contact-alteration by the Inner " Granite ".

Kersantites with a multitude of stout little crystals of biotite are represented by specimens (S 8823, 14423, 14428, 14438), all cutting the Outer " Granite " of Ben Nevis. Here again it is difficult to be sure how far these dykes have been altered by the Inner " Granite ". Early phenocrysts of olivine or augite are replaced by clusters of pale amphibole.

Intermediate to Acid Hypabyssal Rocks

Microdiorite : Introduction.—A fair number of dykes in the district are closely allied to spessartites and kersantites, but are too felspathic to be included with them among the lamprophyres. As a rule much of their felspar is of medium basicity and gives rather stout lath-shaped sections in the groundmass along with inconspicuous phenocrysts ; while quartz fills minute interspaces. Typically these felspathic relatives of the lamprophyres are of intermediate composition.

In the first edition of this memoir they were called malchites, because, as Flett recognised, they resembled rocks already carrying this name in the Odenwald. It has, however, been found that the type malchite is a contact-altered rock (MacGregor 1931, p. 527) ; accordingly the name has been dropped in the present description in favour of microdiorite, suggested by MacGregor—Kynaston used diorite for corresponding rocks in Sheet 45, to the south.

The microdiorites previously called malchites can be divided into spessartitic and kersantitic varieties, according to prominence of hornblende or biotite as the case may be. Very often both minerals occur together and in several of the slices examined it is probable that the biotites have been reinforced by contact-alteration. Magnetite is an accessory.

Like the lamprophyres these microdiorites are very prone to juvenile reactions ; and it has been found impossible in some cases to distinguish with certainty between juvenile change and subsequent contact-alteration.

In addition there are in the Etive Swarm certain dykes which it seems advisable to class as microdiorite, although they are altogether too felspathic to qualify for the adjectives spessartitic or kersantitic. They were grouped in the first edition of this memoir as " highly felspathic pyroxene-porphyrites " with the remark that, " as their porphyritic structure is but faintly marked, it might perhaps be better to class them with the malchites than the porphyrites ". At the time it had been overlooked that Tyrrell had described similar rocks of like age in Ayrshire as plagiophyres (1914, p. 77, pl. ix, 2 ; see also MacGregor 1939).

In the field, plagiophyres are red-grey rocks of fine-grained holocrystalline appearance, suggesting at the same time lamprophyre and felsite. They characteristically carry a few inconspicuous phenocrysts of felspar along with small black spots that are chlorite pseudomorphs after rhombic pyroxene. These last weather into holes giving a " pock-marked " surface.

In slice (S 12339) there are unusually many, but very small, plagioclase phenocrysts, and also an exceptional number of chlorite pseudomorphs after pyroxene ; while in addition there are a few fresh crystals of augite. Albitisation is pronounced with development of epidote. The chilled edge (S 12340) of the same dyke is a very fine-grained pyroxene-andesite.

In normally crystallised specimens the texture varies between trachytic and orthophyric. The felspar is oligoclase with albitised appearance, sometimes, as noted above, accompanied by epidote (S 12482). The characteristic ferromagnesian mineral (as also in Tyrrell's type material) is rhombic pyroxene replaced by chlorite with indigo polarisation. Augite is subordinate (S 12346). A second chilled edge (S 12347) shows particularly clearly the association of pseudomorphed rhombic pyroxene with fresh monoclinic pyroxene. Other plagiophyre slices from our neighbourhood are (S 11909, 13410). Quartz and magnetite are very minor accessories.

Microdiorite Dykes : Etive Swarm.—In the Etive Swarm microdiorites are most frequent in Glen Etive itself, though here as elsewhere outnumbered by porphyrites.

Wherever they occur they are commonly spessartitic (S 11469, 11473, 11476-8, 11506, 11525, 11540, 11545, 11578, 11581, 11609, 14089, 14116, 14135, 14401-3, 14405). Their general character has been sufficiently described. In (S 11476, 11545) we see, along with phenocrysts of fresh augite, large pseudomorphs in green hornblende that must be after pre-augite olivine or rhombic pyroxene. Slices (S 11609, 11536) may be cited as andesitic representatives of the spessartitic microdiorites. Three other slices (S 12892, 14396, 14400) may also be included though of quite exceptional character. They carry needles of hornblende and minute flakes of biotite enclosed in a subvariolitic felspathic base.

Kersantitic microdiorites are less frequent (S 11467, 11474, 11501, 11541, 12894, 14406, 14412, 14415-6). Hornblende is always present in addition to biotite, and there is no sharp line of separation between the spessartitic and kersantitic varieties. In the analysed specimen (Anal. 18, Table 2 ; S 14406) there is a group of comparatively large phenocrysts of almost colourless augite accompanied by uralitic pseudomorphs after olivine or rhombic pyroxene ; but most of the rock consists of oblong zoned andesine, with idiomorphic biotite and hornblende, and a small proportion of interstitial quartz and alkali-felspar.

The plagiophyres of the Survey collection have already been enumerated. It is easy to obtain specimens of these pock-marked dykes in the vicinity of Stob Mhic Mhartuin.

Microdiorite Dykes : Ben Nevis Swarm.—J. G. C. Anderson considers that there are almost as many microdiorites in the Ben Nevis Dyke-Swarm as porphyrites.

In the Geological Survey collection (S 8563, 14424, 14426-9, 14437, 14439, 14441) may be classed as spessartitic, and (S 8821, 14049, 14440, 14442-3) as kersantitic. There is no original feature in which these rocks differ from representatives in the Etive Swarm. Some of them owe part of their biotite to baking by the Inner " Granite " of the Ben Nevis Complex.

Porphyrite : Introduction.—The porphyrites are in large measure intermediate (corresponding with the plutonic banatites and tonalites), but their range extends well into the acid (corresponding with the adamellites).

Porphyrite is here used in Teall's sense to denote rocks with hornblende or biotite, in which phenocrysts of plagioclase are conspicuous without accompanying phenocrysts of orthoclase or quartz. The plagioclase phenocrysts mostly occur in stout tables under 3 mm long, and usually consist of oligoclase or andesine, though occasionally (S 14404) of labradorite. In the field the porphyrites are more often red than grey.

Exceptionally the dominant ferromagnesian phenocrysts are pyroxenes. A dyke (S 11908), cutting the Glen Coe lavas, is a pyroxene-bearing porphyrite with abundant phenocrysts of andesine and pale-green augite, reaching up to 3 mm long, accompanied by equally numerous pseudomorphs in chlorite after rhombic pyroxene. The base is felspathic with quartz, magnetite, biotite and hornblende as accessories. In another case (S 14048a), from Ben Nevis, the phenocrysts are zoned andesine and hypersthene, in separate crystals and glomeroporphyritic groups. The groundmass consists of plagioclase and orthoclase, with accessory hornblende, biotite and magnetite. The rock has been contact-altered, but there is no doubt that hypersthene was present before this happened.

Biotite and hornblende are the most frequent ferromagnesian phenocrysts, often idiomorphic. The hornblende is generally green, but sometimes brown. Exceptionally a dyke is met, which combines the character of a porphyrite and a spessartite through carrying two well developed generations of idiomorphic felspar, hornblende and biotite, as in (S 11544) from Glen Etive —this dyke also contains pseudomorphed phenocrysts after rhombic pyroxene (*cf.* S 11572). More often the ferromagnesian constituents, though well developed among the phenocrysts, do not recur prominently in the groundmass (S 11537, 11567), or *vice versa* (S 14404).

The groundmass of porphyrites (S 11539, 14404) often resembles that of the spessartitic or kersantitic microdiorites ; but more frequently it takes the form of small laths of plagioclase embedded in subordinate micropegmatite (S 9131), or else is microfelsitic (S 12496).

There are two analyses of hornblende-porphyrite dykes in Tables 2 and 3. One (Anal. 14) has been quoted from Walker, and represents a grey rock in the middle of the intermediate suite with a composition much the same as that of the grey tonalite of Ballachulish (Anals. 10, 13). It is probably a member of the Ben Nevis Swarm. The other (Anal. 22 ; S 14398) belongs to a dyke of the Etive Swarm, which has phenocrysts of oligoclase with a few small prisms of pale green hornblende and some biotite. The base consists of stumpy crystals of oligoclase, with interstitial alkali-felspar and quartz. Magnetite, apatite and sphene are accessories, and chlorite and epidote are alteration products. The rock is compact and pink in hand specimen, with an acid appearance that corresponds with its SiO_2 percentage of 66·71. It agrees closely in composition with the porphyritic member (Subzone 4, Anal. 21) of the Outer " Granite " of Ben Nevis.

Porphyrite Dykes : Etive Swarm.—Most of the porphyrite specimens in the Geological Survey collection come from the Etive Swarm. They may be grouped as follows :

(1) Porphyrites with augite phenocrysts corresponding roughly with the plutonic banatites : fresh augite occurs in slices (S 11502, 11539, 11554, 11577, 11908, 12340, 14090) and pseudomorphs after augite in (S 11479, 12493).

(2) Porphyrites with groundmass of spessartitic or kersantitic microdiorite : (S 6560, 11538, 11544, 11549, 11563, 11572, 11577, 14395, 14397, 14404, 14414).

(3) Porphyrites with more or less granophyric groundmass corresponding in many cases with the adamellites : (S 9131, 11480, 11496, 11537, 11547, 11551, 11557-8, 11560, 11566, 12496, 13411, 14108, 14115, 14175, 14178, 14398, 14399, 14410) ; occasionally small phenocrysts of augite are found in such rocks (S 12900, 13757-8, 13760).

(4) Porphyrites approaching quartz-porphyry and obviously thoroughly acid : (S 11907, 12336-7, 12898, 13756, 14087) ; (S 12337) carries a few small phenocrysts of quartz.

Some of the rocks quoted above have been affected by contact-alteration, a matter dealt with in chapter xviii. Albitisation, too, is widespread and may be accompanied by crystallisation of epidote (S 12494).

Chilled edges are extremely well marked among the porphyrite dykes. It was noted that such chilled edges may carry skeletal phenocrysts of felspar (S 11466, 11470, 11548, 11555—the two last are from the same occurrence). In the light of this evidence a large number of well crystallised slices were examined, and it was found that the plagioclase phenocrysts fairly commonly gave suggestions of having passed through a skeletal phase of development. This is specially well seen in slice (S 11547), the crystalline interior of the chilled edge (S 11548, 11555). The matter certainly deserves special research to see whether these suggestions can be verified or shown to be misleading.

Another feature of interest is that three junction specimens (S 11466, 11548, 11555) show marginal micro-brecciation of country-rock. Another (S 11470) gives a clean contact. In still another (S 11532), cut to show a contact between quartz-porphyry and later porphyrite, the country-rock (porphyry) has suffered micro-brecciation along the contact ; but in this case the porphyrite does not exhibit marginal chilling, instead appearing to be a breccia, quite possibly an explosion-breccia.

Porphyrite Dykes : Ben Nevis Swarm.—Five sliced specimens of porphyrites in the Geological Survey collection can be grouped in the same fashion as those of the Etive Swarm, though they come from within the aureole of the Inner " Granite " of Ben Nevis :

(1) With augite : (S 14048a), already described.
(2) With microdioritic groundmass : (S 8820, 14422).
(3) With more or less granophyric groundmass : (S 8819, 14425).

THOROUGHLY ACID TO ULTRA-ACID HYPABYSSAL ROCKS

Felsite : Introduction.—The felsite intrusions of Sheet 53 are pink compact rocks in which small phenocrysts of alkali-felspar are a common, but very subsidiary, feature. The groundmass consists of cryptocrystalline aggregates grouped about crowded centres. These aggregates are generally irregular (S 12342), but sometimes develop into spherulites (S 11041). Associated intrusive rhyolites show very little devitrification, and are often flow-banded (S 11051, 13401).

Felsite Dykes of Ardgour.—The big east-north-east dykes either side of Glen Tarbert are very typical felsites (S 10940).

Felsite Intrusions of Glen Coe District.—Fig. 33, p. 196, shows the outcrops of a number of early felsite and andesite intrusions in the Glen Coe district. Certainly most, possibly even all, of the felsites south-east of Loch Linnhe are earlier than the Etive Dyke-Swarm, in which acid representatives are mainly porphyrites or porphyries.

Slices (S 11051, 12341-2, 13401) come from a broad dyke along the main Boundary-Fault of the Glen Coe Cauldron, west of Meall Dearg, and (S 12344) from a branch of this fault north-east of Meall Dearg (both are shown in Fig. 23, p. 156). Of these (S 12341) is in part xenolithic and breccioidal ; while (S 12342, 13401) come from a central rhyolitic member, cutting (S 12341) and noteworthy for carrying aggregates of well defined micropegmatite. These are sometimes irregularly bounded, but sometimes have the outlines of component felspars. They greatly resemble a photomicrograph from the Braemar district (Flett 1905, pl. vii, 1 ; see also 1899).

The slice (S 12344), from the branch of the Boundary-Fault north-east of Meall Dearg, and (S 11460-3) from Beinn Ceitlein, Glen Etive, afford good examples of contact-alteration.

Slice (S 11041) has already been mentioned for its spherulites. It is from an early felsite dyke cutting the Glen Coe lavas.

Slice (S 12343) is from a conspicuous branching dyke on Garbh Bheinn, on the south side of Loch Leven. The various branches of this dyke run E.N.E., N.E. and N., and are cut by neighbour N.E. porphyrites. The whole may perhaps antedate the Etive Swarm, or it may be just an early member of the same. It is more porphyritic as regards alkali-felspar than the usual felsites, but carries scarcely any phenocrysts of quartz.

Quartz-Porphyry Dykes, Etive Swarm.—While it is not absolutely certain that any of the felsites of the district belong to the Etive or the Ben Nevis Dyke-Swarm, there are quite a few quartz-porphyries undoubtedly referable to the former. One at least is thought to have been fed by the Meall Odhar ring-dyke of binary granite (pp. 172, 201).

The quartz-porphyries carry fairly conspicuous phenocrysts of alkali-felspar and quartz. The felspar phenocrysts are generally tables between two and three millimetres long, and are mostly untwinned or simply twinned—though albite twinning can often be detected. They are seldom clear. Quartz phenocrysts show crystal faces though with rounded angles. They are generally subordinate, but are well represented in the analysed specimen (Anal. 33, Table 3 ; S 14114). Biotite phenocrysts are almost always present. Hornblende is rare, but one prism, seen in (S 12481), is 4 mm long. The groundmass varies from felsitic, with micrograpnophyric textures grouped about little alkali-felspars (S 11481, 12481), to aplitic, with small quartz grains scattered among crystals of alkali-felspar of about the same size (S 11546, 14114).

Quartz-porphyry slices in the Geological Survey collection may be distributed among five dykes of the Glen Etive district. These can be recognised on the one-inch map from N.W. to S.E. as follows :

(1) Member (not separately coloured on Sheet 53) of the Allt Fhaolain multiple dyke illustrated in Fig. 34 : (S 14413).

(2) Discontinuous dyke, Stob na Bròige to W. of Stob Dearg : (S 11481, 12479, 12481, 12519).

(3) Dyke passing quarter of a mile E. of Alltchaorunn : (S 12518).

(4) Dyke passing 1 mile E. of Alltchaorunn : (S 11535, 11546, 14114—Anal. 33, Table 3).

(5) Dyke passing 1½ mile E. of Alltchaorunn : (S 9130, 11565, 11568).

Dyke (3) is the one almost certainly fed from the Meall Odhar binary granite. Dyke (5) has given a granitic specimen (S 11568) where it is mapped as terminating half a mile from this granite outcrop—which rather suggests that it too may have been fed from this source.

Quartz-Porphyry Boulders in Lower Old Red Sandstone Conglomerates.—A feature of the Lower Old Red Sandstone conglomerates of Glen Coe is their extremely small content of boulders or pebbles of hypabyssal crystallisation ; but Kynaston collected a specimen of felsitic quartz-porphyry with quartz phenocrysts ranging up to 2·5 mm across (S 10289).

BASIC TO SUB-BASIC LAVAS

Basalt and Allied Pyroxene-Andesite Lavas, Glen Coe.—Though well developed in the Glen Coe succession, and even more so in Lorne, basalts and allied pyroxene-andesites are absent from Ben Nevis. In Glen Coe they are dark compact rocks of a blue-black colour when fresh, but often mottled, purplish, and pistachio-green through decomposition. The compact texture of even the most basic types suggests andesite rather than basalt in hand-specimen. Olivine pseudomorphs can, however, often be recognised owing to their red, flaky character coupled with their shape. The red material is a haematitic residue after iddingsite. The lavas are generally very inconspicuously porphyritic.

An unusually fresh example of olivine-basalt (Anal. 3, Table 2 ; S 9628) has been analysed from near Taynuilt in Lorne (Sheet 45, Geol.). It carries numerous pseudomorphs, up to 1·5 mm long, after olivine in serpentine, talc and iron ore. The groundmass is well crystallised and consists of 0·5-mm laths of andesine or labradorite, small idiomorphic prisms of pale-green augite, octahedra and rods of magnetite, and a cement of alkali-felspar—in which Analysis 3 shows there must be considerable potash (see p. 208).

Two slices from Glen Coe (S 10317, 14134) are very similar to the Taynuilt specimen, but not so fresh ; and it is very doubtful whether they contain as much potash. Another (S 14409) is of finer texture, as also (S 11615)—the flow with withamite amygdales (p. 138). Occasionally fresh phenocrysts of augite accompany the olivine pseudomorphs in well characterised olivine-basalts (S 10319, 14104).

Analysis 5, Table 2 (S 14408), from the Glen Coe area, represents an olivine-free basalt, which carries a number of small chlorite pseudomorphs after rhombic pyroxene in a groundmass of short unoriented plagioclase laths with sparse little prisms of augite and scattered iron ore. The analysis shows that this rock is basic and close in composition to the Taynuilt lava (Anal. 3), except that its potash is lower. Similar types are seen in other slices (S 10314, 10316, 11042, 12490, 12772, 39706). In the first two of these, olivine appears to be represented by pseudomorphs. In another slice (S 10318), little augite phenocrysts are seen, and apparently there are no pseudomorphs after olivine. In still another (S 9716), from Càm Ghleann, there are numerous phenocrysts of augite up to 1 mm across, pseudomorphs suggesting rhombic pyroxene, and scattered phenocrysts of plagioclase up to 2 mm.

The felspar laths of the base in the slice (S 39706) listed above are sufficiently parallel to give trachytic texture. Finer- and much finer-grained texture is found in other cases (S 11044-5, 11616, 12436), all collected from Group 1 of Fig. 20, p. 133. It is quite possible that these finer-grained types are andesites ; but the condition of the material does not warrant an attempt to separate pyroxene-andesites from basalts. Where trachytic texture is developed, some of the Glen Coe and Lorne lavas, under the microscope, closely resemble mugearites as described from the Scottish Tertiary and Carboniferous. They lack, however, the platy fluxion so characteristic of mugearites in the field.

INTERMEDIATE LAVAS

Hornblende- and Biotite-Andesite Lavas of Glen Coe and Ben Nevis.—The hornblende-andesites of Ben Nevis are of special interest as having furnished Teall (1888, p. 287 ; pl. xxxvii) with the first good British instance of the type. It is now known that hornblende-andesites are widely developed among lavas of Old Red Sandstone age elsewhere in Scotland ; and nowhere, as Kynaston has shown, more typically than in Glen Coe.

There may be slight differences distinguishing the Ben Nevis and Glen Coe examples. For instance, the hornblendes of the former (S 8824, 8826, 8828, 13736-8, 13741-2, 14025, 14030, 14032-3, 14036) seem often to be greenish, while those of the latter (S 9132, 9164, 10321, 11583, 11590, 14576) appear to be more definitely brown. Moreover, it may be a related fact that biotite-andesites are commoner in the Ben Nevis collection (S 14026-9, 14035, 14037) than in that from Glen Coe (S 11043, 11614). In either district transitional types occur in which both hornblende and biotite phenocrysts are well developed (S 14036, Ben Nevis ; 9132, 11579, Glen Coe).

Dacites, with abundant phenocrysts of quartz, oligoclase, andesine, hornblende and biotite in a fluxional devitrified base, have been collected by Grabham on Stob na Bròige north-east of Dalness (S 11605, 12761, 12765-6, 14407). They are closely related to associated rhyolite lavas, with which indeed they have been mapped.

In hand-specimens the hornblende- and biotite-andesites are of even finer texture than the basalts and pyroxene-andesites. They are of a dull green colour which changes to purplish or greenish grey on weathering. Usually they contain abundant small felspar phenocrysts along with prisms of hornblende or plates of biotite, all of which are visible to the unaided eye, though not so conspicuous as in the porphyrites.

Under the microscope the small felspar phenocrysts prove to be andesine or labradorite, sometimes beautifully zoned (S 14030). The hornblende and biotite have almost invariably suffered magmatic resorption, producing a black border of iron oxide. Within this border the hornblende is generally replaced by chlorite, calcite or epidote. Kynaston noted a few small augite phenocrysts in two examples (S 9179, 10321). There are also fairly frequent chloritic or uralitic pseudomorphs (S 2054, 11590, 14032), which, as Maufe has suggested, may be after rhombic pyroxene. Little apatites may sometimes figure as phenocrysts (S 14102).

In a few cases phenocrysts are so poorly developed that the andesites are nearly non-porphyritic (S 2054, 9714, 11604).

The groundmass is commonly composed of minute felspar laths and cryptocrystalline material, often with innumerable dust-like crystals of magnetite. On the assumption that much of the cryptocrystalline material represents glass the prevalent groundmass texture is pilotaxitic grading to hyalotaxitic (S 14031), on the one side, and to microtrachytic (S 11599), on the other. One example of biotite-andesite (S 14037) is microspherulitic. Flow-orientation may be well developed (S 11584, 13770). Flow-brecciation is also common.

The analysed specimen from Glen Coe (Anal. 16, Table 2 ; S 14576) is typical, with well marked phenocrysts of brown hornblende and labradorite to oligoclase-andesine. The hornblendes within their black rims are unusually fresh ; but the plagioclase is considerably attacked. The base is hyalopilitic and altered. Chemically this andesite agrees closely with the banatitic Subzone 2 of the Outer " Granite " of Ben Nevis (Anal. 15).

Representative slices from Glen Coe not mentioned above include (S 9155, 9165, 9718-9, 11586, 11589, 11592-3, 11601, 11608, 11912, 12473, 13771, 14101, 14132-3). Others, both from Glen Coe and Ben Nevis, will be cited in the next chapter where contact-alteration is discussed.

ACID AND ULTRA-ACID LAVAS

Rhyolite Lavas of Glen Coe.—The rhyolite lavas of Glen Coe are the finest development of the type in Britain. They vary greatly in colour. They may be reddish-purple, grey, brown or even black. They are generally distinguishable in the field by their tendency to weather a pale tint, their frequently pronounced fluxion, their flinty fracture and the rarity of ferromagnesian phenocrysts, among which biotite alone occurs. Also they furnish particularly massive crags.

Under the microscope they are found to be thoroughly leucocratic. Plagioclase felspar, near albite, may occur as small scattered phenocrysts, in some cases accompanied by a fair proportion of quartz (S 9134, 9141, 9144, 9152-3, 10331, 11491, 11588, 12776-7), in others, more or less alone (S 9135, 9137, 9145-6, 9726, 11596, 12471). As the proportion of phenocrysts decreases the texture approaches or attains to non-porphyritic (S 9136, 9138, 9143, 9725, 9727-8, 12469, 12472, 12489, 12937, 14100, 14105).

The analysed specimen (Anal. 32, Table 3 ; S 14100) is chemically very similar to the Quartz-Porphyry (Anal. 33), though it is itself almost non-porphyritic with a few albitic phenocrysts in a somewhat banded, devitrified base that shows microlites of alkali-felspar.

Occasionally quartz phenocrysts in these rhyolites have skeletal form due either to growth or corrosion (S 9144, 10331). Biotite, generally pseudomorphed, may occur in small amount (S 9145-6, 12776). Minute flakes of fresh muscovite appear sometimes to be of igneous origin (S 9728, 12471), though possibly detached from schist xenoliths.

The groundmass is fairly often cryptocrystalline, suggesting original glass ; but more commonly it is patchily microfelsitic (S 9145, 10331) and may have reached this stage when the rock consolidated. Perlitic cracks have only been noted in one case (S 9135). Microspherulitic growths are also uncommon (S 9136, 9143). Quartz has often developed in small granular aggregates (S 9727), in certain cases occupying original cavities.

Beautiful flow-banding is common (S 9143, 9725, 9727, 11491, 12776-7). As Kynaston early recognised, many of the rhyolite flows are extremely xenolithic, enclosing fragments of rhyolite, andesite (probably also basalt) and schist (S 9152, 11491, 12776-7).

E. B. B.

CHAPTER XVIII

ROCKS OF LOWER OLD RED SANDSTONE AGE CONTACT-ALTERATION DUE TO PLUTONS

CONTACT-ALTERED SCHISTS SOUTH-EAST OF LOCH LINNHE

Introduction including Regional Metamorphism.—The various " granites " of the district were intruded into the schists after the latter had attained a low to medium grade of regional metamorphism. The " granites " have locally effected an easily recognisable alteration of a different type ; new minerals and new textures have been produced, and the final result is a complete transformation. In the field the alteration reveals itself in such matters as loss of fissility, increased hardness, change of colour, and, in many cases, in the production of spots and sometimes of definite recognisable crystals. The features enumerated above are restricted to well-marked aureoles round about the " granites," and admit of fairly accurate mapping (Fig. 39).

The " granites " are surrounded by a heterogeneous assemblage of schists, and the range of their influence is correspondingly varied. It is found, for instance, that impure limestones have been particularly susceptible, and have been converted into calc-silicate-hornfelses at distances ranging up to 1¾ miles from the margins of the various intrusions. Phyllites have been more stable, and are seldom noticeably hardened more than three-quarters of a mile from the " granites ". On the other hand pyrites is more susceptible than even calcareous material (p. 251).

Introduction of magmatic felspar seems to have occurred to an important extent in the aureole of the Fault-Intrusion of Glen Coe (pp. 157, 219) ; and pronounced reactions with xenoliths have been carefully studied. Still, most of the changes which have taken place in the schists during contact-metamorphism appear to have depended upon simple reconstruction of the material already present, and upon a certain amount of expulsion of the volatile constituents, mainly carbon dioxide and water. It is an open question how much of these volatiles passed outward through country-rock, and how much inwards to be dissolved in magma. If much was taken into solution, it is probable that a considerable proportion was eventually discharged in volcanic explosions.

In its more important features the contact-metamorphism in the present district is identical with that of the Pass of Brander country to the south, already described by Teall (*in* Sum. Prog. 1899, pp. 83-8) and Kynaston (*in* Sum. Prog. 1898, pp. 88-90 ; Kynaston, Hill and others, 1908, chap. x). Its phenomena are also closely similar to those recorded from other West Highland districts, such as Kilmelfort (Kynaston 1909, pp. 71-2), Glen Fyne—Garabal Hill (Clough 1897, pp. 98-101) and the Ross of Mull (Bosworth 1910).

Macculloch's account (1817, p. 126) of the marginal relations of the Ballachulish " Granite " affords the first reference to the phenomena of contact-alteration in Sheet 53. Professor Judd's short description (1874, p. 292) of the metamorphism produced in the schists by the Ben Nevis " Granite " is also worthy of note. Later, during the Geological Survey's work in the district, the subject has been frequently dealt with by the various members of the staff. Brief references and more detailed descriptions have thus from time to time appeared dealing with the contact-alterations of the schists due to the Ben Nevis (Ann. Rep. 1896 ; Sum. Prog. 1898, 1899, 1901), Mullach nan Coirean (or Meall a' Chaoruinn) (Sum. Prog. 1899), Ballachulish (Ann. Rep. 1897 ; Sum. Prog. 1903, 1904, 1905), Glen Coe (Sum. Prog. 1905 ; Clough, Maufe and Bailey 1909, pp.

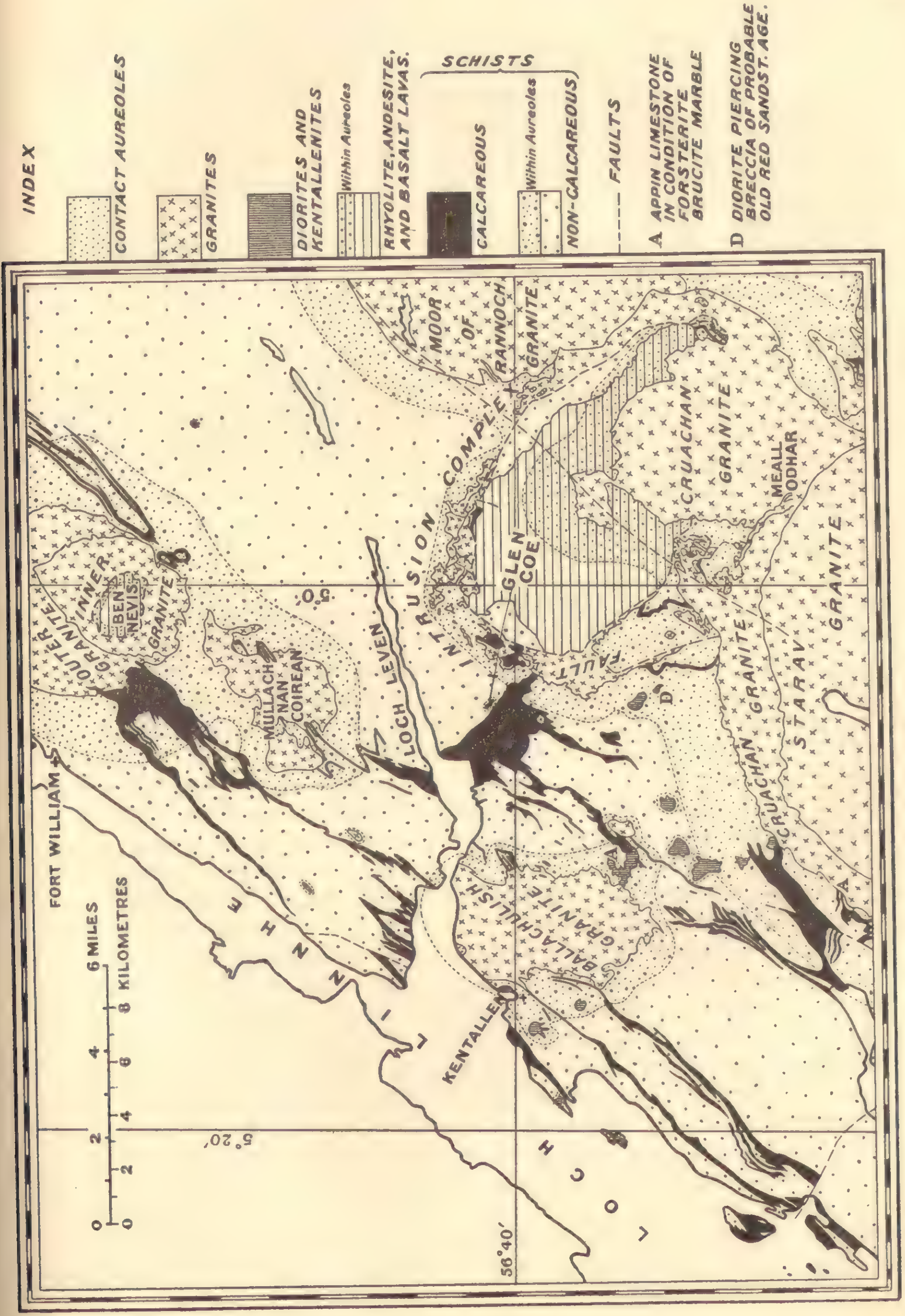


FIG. 39. Map of contact-aureoles south-east of Loch Linnhe
The limits drawn include alteration sufficiently intense to convert impure limestone into calc-silicate-hornfels

636-8) and Cruachan (Sum. Prog. 1899, 1905) "Granites," and to the neighbouring smaller masses of diorite and kentallenite (Sum. Prog. 1905). The upshot is that Grant Wilson, in particular, clearly established the existence of definite contact-aureoles around the various plutonic masses, and that, in specimens from these aureoles, Teall, in the first instance, recognised actinolite, tremolite, malacolite, andalusite, and cordierite. All who have mapped in the district are agreed as to the distinctive characters assumed by the schists within these aureoles ; in fact, it takes much experience of the district to correlate individual groups of the schists within and without the contact-aureoles.

In preparing the corresponding chapter in the 1916 edition of this memoir the writer received much assistance from Flett. What follows is very little altered, save that the rest of this introduction is devoted to a short summary regarding pre-contact regional metamorphism. Also advantage has been taken of three important papers, one by Neumann (1950, *see* Ballachulish Slates below), and two by Muir (1953a,b, *see* Appin Limestone and Quartz Xenoliths).

The main facts of distribution of *regional metamorphism* in Sheet 53 have been established by a number of workers, and, since the 1916 edition, have been made the subject of a couple of papers (Bailey 1923a ; Elles and Tilley 1930). It is agreed by all that an ill-defined curving metamorphic boundary can be traced southwards from Fort William right across Sheet 53. West of this boundary grey pelitic sediments do not carry garnet, while to the east they very often do. Such a boundary is now termed an isograd.

The garnet isograd, starting from Fort William, reaches the north shore of Loch Leven a little west of the Glen Coe Quartzite outcrop, one mile east of Ballachulish Ferry. It then crosses the Loch to include on its garnet-bearing side a considerable proportion of the Leven Schist outcrop at the roadside east of the Ballachulish Pluton. From here it must swerve eastwards for about three miles, very probably with a bulge to the north-east somewhat as shown by Elles and Tilley in their coloured map. At any rate, turning south again it crosses Allt Socach a little upstream from the outcrop of the Sgòrr a' Choise Slide, and next, three miles to the south-west, the River Creran above the Salachail diorite. Then two miles farther still it passes close to Glenure House.

The garnetiferous belt to the east generally begins with a wide stretch of country in which garnet is merely an inconspicuous accessory. Eventually, however, the mineral becomes very prominent, for instance in the Leven Schist spread south of the An t-Sròn "Granite" and east of the Beinn Fhionnlaidh outoutcrop of Glen Coe Quartzite towards Glen Etive. Blades of actinolite commonly accompany abundant garnet.

In Sheet 62 (Geol.), north of Sheet 53, the type outcrop of Leven Schist runs north-east towards Glen Spean into a highly garnetiferous region like that of Glen Etive. In Sheet 53 again, the Reservoir Schist passing the Blackwater Reservoir is in parts rich in garnet and actinolite.

In the other direction, west of the Fort William—Glenure line, metamorphism wanes, and the garnet zone is separated by a biotite zone from a chlorite zone in which biotite is wanting. The outcrop of the Eilde Flags at Fort William carries garnet, according to Elles and Tilley ; but it has reached the chlorite zone before it finally goes out to sea west of Onich. The Appin Phyllites further east at Onich are still in the biotite zone ; though rather unexpectedly the westernmost part of the Leven Schist outcrop north of Ballachulish Ferry seems to be in the chlorite zone. This alternation from west to east from chlorite to biotite and back again to chlorite may perhaps be due to the interaction of two opposing tendencies : (1) there is a tendency for the regional metamorphism to increase eastwards irrespective of structural position ; (2) there is also an independent tendency, as we shall see demonstrated in Glen Coe, for this metamorphism to decrease at structurally higher levels ; and it so happens that eastwards, between Onich and Callert, beyond Ballachulish Ferry, one is dealing with a structurally ascending sequence. On the other hand it is possible that the Appin Phyllites at Onich have proved more susceptible to metamorphism than the Leven Schists north of the Ferry. One cannot be certain.

South of the mouth of Loch Leven Elles and Tilley have found biotite continuing in the Appin Phyllites south-west as far as Cuil Bay ; though they note that it does not occur in the adjoining carbonaceous Cuil Bay Slates. We shall return to this last point presently. Meanwhile we note that the same authors place the south-west continuation of the Appin Phyllite outcrop, beyond Cuil Bay, into the chlorite zone, along with the greater part of the Leven Schist outcrop that lies to the east.

Much the most important phenomenon connected with regional metamorphism in Sheet 53 is the down-throw of slightly metamorphosed Leven Schist within the cauldron-subsidences of Glen Coe and Ben Nevis against much more obviously metamorphosed Leven Schist outside (pp. 71, 179). This long ago convinced Maufe (and now the writer) that the regional metamorphism of the district diminishes upwards. Accordingly we may interpret the garnet zone of the eastern half of Sheet 53 as dipping beneath the biotite and chlorite zones further west. Readers must consult Elles and Tilley (1930) for an alternative interpretation.

As might be expected the maps illustrating the writer's (1923a) and Elles and Tilley's (1930) publications agree fairly closely ; but the 1930 map is superior in that it sets out to distinguish biotite and chlorite zones—the 1923a map merely shows where mica is conspicuous or inconspicuous as the case may be. Also Elles and Tilley are probably right in interpreting the eastward swing of the garnet isograd from the Ballachulish pluton to Allt Socach as connected with the pitch-depression that takes the outcrop of the Ballachulish Slide along Lower Glen Coe. On the other hand, it seems that these authors have sometimes been misled by not sufficiently recognising what a contrast of metamorphic response may be expected from rocks of different chemical composition. In the first edition of this memoir the following observation is recorded :—The Ballachulish Slates " have a very fine crystallisation, much finer than that of the Leven Schists on the one side of them or of the Appin Phyllites on the other. This denotes a selective metamorphism which is probably connected with the large amount of finely disseminated carbon present in the group " (Bailey *in* Bailey and Maufe 1916, p.202). Further experience in Scotland has confirmed such delay of metamorphism in carbonaceous rocks ; and similar behaviour has been found in other countries. If allowance is made for this phenomenon, there is no reason to follow Elles and Tilley (1930, fig. 7) and admit a *mechanically induced* " break " in metamorphism associated with the Ballachulish Slide on the west side of the Callert exposure of the Ballachulish Core (Fig. 8, p. 50).

In conclusion one may recall, what is familiar to all Scottish geologists, that the mapping of metamorphic zones with reference to first appearance of certain selected index minerals was initiated long ago by George Barrow working in the East Highlands.

In what follows regarding the contact-metamorphism of the schists, the various formations are taken in order according as they are calcareous, dolomitic, pelitic or psammitic.

Ballachulish Limestone.—In its purer portions the Ballachulish Limestone, where not affected by the " granites," is a dark-grey finely crystalline limestone with quartose bands and occasional cubes of pyrites (S 15374). The grey tint is due to disseminated black carbonaceous dust. Pale brown phlogopite and muscovite both occur as minor constituents. The following is an analysis by B. Lightfoot from Allt Socach (S 15374): SiO_2 12·70 ; Al_2O_3 4·10 ; Fe_2O_3 2·44 ; MgO 1·98 ; CaO 42·21 ; H_2O 0·91 ; CO_2 35·98 ; total 100·32. Restated in terms of major carbonates this gives : $CaCO_3$ 75·3 ; $MgCO_3$ 4·1 ; etc., 20·9.

More impure portions of the limestone (S 12367, 15375) contain much dolomite (determined by rough chemical tests), quartz, mica, and chlorite ; the mica is in part muscovite, and in part a phlogopite approaching biotite, but not nearly so dark as the biotite of the pelitic schists of the district ; the chlorite is colourless and often polysynthetic, and has a birefringence about equal to that of quartz ; it appears to be primary (S 12367), and occurs in the same way as the mica (*cf.* Flett 1902, p. 48). Irregular granules of sphene are also present in small amount. Regional tremolite has been recorded from the north shore of Loch Leven near Callert House, and across the loch at Bridge of Coe (Elles and Tilley 1930, p. 640).

Minute pea-like concretions may occasionally be noted on the surface of the limestone : in some cases these consist of quartz and chlorite (S 15429), in others of alkali-felspar with poikilitic inclusions (S 11050, 39694, p. 74) ; similar spots of alkali-felspar are well-known in the pelitic schists of this and other districts.

Much of the Ballachulish Limestone is very impure (S 15429-15431), with calcareous matter occupying merely a subordinate position.

Contact-alteration of the purer type of Ballachulish Limestone has been studied in a suite of specimens taken from the western slopes of Glen Nevis (S 15432-4, 15437-8) in the neighbourhood of the overlying Ballachulish Slates—here in the condition of hard, black, spotted cordierite-hornfels (Fig. 3, p. 39). The purer bands of the limestone retain their dark colour and the main part of their carbonates ; they have, however, lost their disseminated quartz, where this was accompanied by other impurities in the original, and have developed numerous porphyroblastic crystals of tremolite ranging up to about an inch in length, and darkened with included carbon (S 15433). Similar crystals of tremolite are abundant in the Ballachulish Limestone outside the area of the map in the Spean section (Sheet 62, Geol.), north of Ben Nevis, where they owe their origin to regional metamorphism ; but in Glen Nevis their restriction to the aureole of the Ben Nevis " Granite " renders it probable that they are of contact-origin. The dark tremolite-bearing limestone of Glen Nevis alternates with thin seams of calc-silicate-hornfels of the type to be described below. Nothing of the kind is found in the Spean, or for that matter anywhere in this neighbourhood outside the aureoles indicated in Fig. 39. These seams represent more impure laminæ in the original limestone ; at some distance from the margin of the Ballachulish Slates carbonate in bulk is no longer encountered, and the whole deposit is in the condition of calc-silicate-hornfels.

South of the Ballachulish " Granite " the purer part of the Ballachulish Limestone has suffered an interesting type of alteration which extends for a mile beyond the aureole drawn on the map. It loses much of its dark tint and, when freshly broken, emits a strong fœtid odour. This is due to decomposition of pyrites (p. 251).

Dark limestones, or marbles, still rich in carbonates, are found among the representatives of the Ballachulish Limestone in the lower limb of the Ballachulish

Fold within the contact-aureole of the Cruachan "Granite," east of Glen Creran. These occurrences are in Sheet 45 (Geol.), but their distribution is stated in Section F, Chapter vi.

Contact-alteration of the impure parts of the Ballachulish Limestone has usually resulted in the production of a fine-grained, pale-green or white, banded calc-silicate-hornfels. A small proportion of original calcareous material, after alteration, sets its stamp upon this hornfels, so that the distinction between impure Ballachulish Limestone and adjoining pelitic schist is accentuated, rather than otherwise, within the aureoles (Glen Nevis, S 6238-9, 8279, 8280, 15435-6, 15439-15443 ; Aonach Beag, S 13836, 13923 ; Glen Coe, S 11048-9, 15871-2, 39692-3 ; Windows of Etive, S 11485-6, 11625 ; Beinn Ceitlein, S 11449).

Carbonates and quartz are only sparingly represented. The micas and chlorites have also been extensively attacked. Considering the variety of composition of the original limestone it is surprising to find that the contact minerals set up are few in number. Tremolite, malacolite (colourless diopside), and alkali-felspar are met with again and again. Epidote and zoisite are much more rarely found. Basic felspar has only been noted in a single slide (S 11486), while wollastonite, garnet and idocrase have not been identified. As a matter of inference a portion of the calcite present may be regarded as of contact-origin resulting from dedolomitisation during the formation of tremolite. Sphene and rutile have recrystallised as accessory minerals.

Banded structures representing bedding are often prominent in these altered rocks. Some of the bands have a finely crystallised groundmass of tremolite, or closely related pale-coloured amphibole ; their fracture tends to be rough, porous, and fibrous, and their colour varies in the hand-specimens from greenish-white (S 6239) to nearly black. Other bands consist mainly of malacolite in small ragged crystals or finely granular aggregates, often associated with alkali-felspar ; their fracture is very compact and flinty, and their colour is almost white (S 6238, 8280, 15442). Some thin black seams consist of undecomposed phlogopite (S 15443).

While the calc-silicate-hornfelses are generally fine-grained, Peach and Maufe found a coarsely crystalline variety in the low, rocky ground south of the Glen Coe road, 400 yards W.N.W. of Clachaig Hotel. In the hand-specimen this variety is very beautiful, owing to an abundance of pale-green tremolite in stout prisms. Under the microscope the groundmass is seen to consist of alkali-felspar and malacolite, with undecomposed phlogopite, chlorite, calcite, and quartz (S 11048). Tremolite also occasionally occurs in large crystals in the calc-silicate-hornfelses of Glen Nevis (S 6238) in the same porphyroblastic fashion as in the associated calcareous bands ; the groundmass in such cases is sometimes rich in tremolite, sometimes in malacolite.

An unusual mode of occurrence for amphibole is represented in a few bands from the transition zone between the Ballachulish Limestone and the Leven Schists in Aonach Beag east of Ben Nevis and in the valley to the north. The amphibole in this case is green and pleochroic, and occurs in broad allotriomorphic crystals, building aggregates which appear as small spots in the hand-specimens ; it may perhaps be replacing garnet. In the same rock (S 13836, 13923) epidote is very abundant, occurring in flat prisms disposed along the foliation. Quartz and felspar are also much in evidence, with subordinate flakes of biotite.

The impression is formed, on looking through a large suite of slides of these calc-silicate-hornfelses, that there is an ill-defined tendency for special association of malacolite and alkali-felspar. Sometimes, as in the tremolite rocks of Glen

Coe already mentioned, the felspar occurs in fairly large crystals and encloses curious confluent beaded aggregates of malacolite, thus giving rise to a variety of poikilitic structure. In other cases where the foliation is fairly well preserved, the felspar is often granular, and the malacolite occurs in ragged crystals or granules (S 6238, 15436, 15442). In all the calc-silicates, lenticular eyes of alkali-felspar and malacolite are met with in which the malacolite occurs in larger individuals with fair crystal boundaries. Occasionally a flinty band is found consisting almost wholly of granular malacolite (S 8280).

An exceptional variety of the metamorphosed Ballachulish Limestone was collected by Maufe, near Clachaig Hotel, Glen Coe, in association with normal calc-silicate-hornfelses well developed at this point. Zoisite occurs in this rock in abundant stout prisms, a couple of inches long, in a base consisting of abundant quartz, muscovite, and phlogopite (S 11049, 15872). From the prevalence of micas and the absence of the normal contact-minerals, it is obvious that the production of the zoisite here must be due to a very low grade of contact-alteration—unless, indeed, it should be referred to an abnormal phase of regional metamorphism.

A limited amount of interaction between the limestone and the invading " granite " can sometimes be made out with fair probability. A specimen (S 15370) collected by Maufe from the Ben Nevis path has an igneous aspect ; it consists in the main of dark greenish-brown hornblende, up to half an inch in length, lying without orientation in a medium-grained allotriomorphic base made up of small crystals of orthoclase, with less abundant oligoclase, malacolite, sphene and a little quartz. The dark hornblende is bordered by pale-green hornblende and malacolite. There can be no question but that this rock is closely linked with the calc-silicate-hornfelses, while the dark colour of the hornblende and the excessively felspathic nature of the groundmass suggest addition of material from the neighbouring " granite ".

Turning now to the texture of the calc-silicate-hornfelses, we have noted already that original bedding is retained intact. Foliation has also in many cases been preserved, although less perfectly ; tremolite, malacolite, and felspar often show a more or less definite orientation, least marked in the case of the felspar. In such cases it is frequently evident that the foliation now apparent is merely a relict structure, and that it was originally determined by the presence of minerals of micaceous habit, subsequently destroyed (S 15440). In other instances it is not uncommon to find the foliation more or less obliterated : the felspars may grow in large crystals, enclosing granular aggregates of malacolite in poikilitic fashion, or the tremolite may build radiating felted aggregates (S 6239).

The *chemistry* of the changes involved in contact-metamorphism of the Ballachulish Limestone has not been investigated by analysis, but certain main principles can be laid down, as a result of microscopic investigation. In the first place, the reactions have proceeded in such a manner as to eliminate, more or less completely, the volatile constituents, carbon dioxide and water—though Allen and Clement (1908, p. 101) have shown that tremolite and malacolite (diopside) both contain water, apparently in solid solution. Another leading principle is that the magnesia at any point has been satisfied with silica before the lime—Teall's dedolomitisation principle (1903).

In no case investigated has the silica : magnesia ratio of the Ballachulish Limestone fallen beneath that required to give tremolite, for brucite and forsterite are absent. The development of tremolite in place of malacolite seems to have been determined by the following conditions. All the magnesia present at any particular point must be accommodated with silica. If possible it enters the compound malacolite, $CaO . MgO . 2 SiO_2$. If there is a deficiency, *either as regards silica or lime*, tremolite, $CaO . 3 MgO . 4 SiO_2$, results instead. Thus it happens that among the altered limestones of Glen Nevis tremolite occurs both in highly calcareous bands, free from quartz (S 15437), and also in highly quartzose bands, free from calcite (S 15441).

The occurrence of tremolite in bands free from calcite, or other lime minerals, such as wollastonite, idocrase, or garnet, immediately suggests a problem—malacolite is not here classed as a lime mineral because its molecular ratio of CaO : MgO is only unity. The production of tremolite from dolomite and silica involves the simultaneous formation of calcite—

$$3(\underbrace{CaO . MgO . 2 CO_2}_{\text{Dolomite}})+\underbrace{4 SiO_2}_{\text{Quartz}}$$

$$=\underbrace{CaO . 3 MgO . 4 SiO_2}_{\text{Tremolite}}+2(\underbrace{CaO . CO_2}_{\text{Calcite}})+\underbrace{4 CO_2}_{\text{Carbon dioxide}}$$

It is true calcite thus produced may elude detection through its power of segregation, or perhaps its lime may be removed in some form in solution ; but in many cases the absence of calcite is probably due to its interaction with non-calcareous ferromagnesian minerals. One must remember that much of the Ballachulish Limestone is a pelitic or psammitic sediment with only a subordinate amount of carbonate. Phlogopite and chlorite are rarely preserved in the calc-silicate-hornfelses, and cordierite, which, as we shall see presently, is the characteristic ferromagnesian mineral of the pelitic hornfelses, is entirely absent. It would appear, therefore, that the phlogopite and chlorite have been destroyed, and that their magnesia has gone to build up tremolite or malacolite, as the case may be.

The destruction of phlogopite and chlorite referred to above is of course accompanied by an expulsion of water. The same principle is involved in the decomposition of muscovite. How important the metamorphism of the micas has been is attested by the abundance of alkali-felspar in the calc-silicate-hornfelses. It would be interesting to ascertain the final destination of the excess of alumina liberated as a result of the change of the micas and chlorite. It seems fairly certain that it, and also the iron derived from phlogopite, chlorite, pyrites, etc., must have been taken up by the pyroxenes or amphiboles so abundantly developed, although the latter agree closely in character, and presumably in composition, with the ideal non-aluminous silicates, malacolite and tremolite (*cf.* Flett 1909, p. 100). It has already been stated that the malacolite of these rocks seems particularly prone to be associated with alkali-felspar, and accordingly it would not be surprising to find that it has accommodated the main part of the excess alumina.

Appin Limestone.—The most prevalent type of Appin Limestone is a cream, pink, or very pale blue magnesian limestone or dolomite (S 15376-8). No staining tests have been undertaken, but the analyses of Table 4 indicate a prevalence of magnesian carbonate not encountered among the purer forms of the Ballachulish Limestone. The texture is fine- to medium-grained.

The Appin Limestone enters the *contact-aureole* of the Ballachulish " Granite " at several points. Specimens taken from exposures a little west of the path leading from Ballachulish to Glen Creran are of exceptional interest, for they recall precisely the features described by Teall (1907, chap. xxxi) as characterising the Durness Dolomite in the aureoles of the Ledbeg Syenite, Sutherland, and of the Skye gabbros and granites.

TABLE 4

Analyses of Appin Limestone

	1	2	3	4	5	6	7	8	9	Dolomite
SiO_2	3·4	13·9	1·9	1·3	3·5	3·3	25·9	3·7	—	—
Al_2O_3	1·2	5·3	1·8	—	2·1	—	5·0	—	—	—
Fe_2O_3	—	5·1	1·3	—	3·3	—	1·8	—	—	—
FeO	0·2	—	—	—	—	—	—	—	—	—
MgO	9·0	8·0	18·5	20·0	17·1	21·8	5·4	20·9	18·4	21·8
CaO	42·5	33·7	31·7	30·7	29·7	29·1	28·9	28·9	26·7	30·4
CO_2	43·1	34·3	44·6	45·9	44·0	46·8	29·3	45·6	41·1	47·8
Etc.	0·5	0·2	0·9	—	—	0·6	4·1	—	13·1	—
Total	99·9	100·5	100·7	—	100·2	—	100·4	—	—	100·0
$MgCO_3$	18·8	15·2	38·0	41·8	35·7	45·7	11·4	43·8	38·6	45·7
$CaCO_3$	75·6	60·0	56·4	54·8	52·9	52·0	51·6	51·6	47·6	54·3
Surplus MgO	0·0	0·8	0·4		0·0		0·0			0·0
Surplus CO_2	0·0	0·0	0·0		2·1		0·9			0·0

1. Waterfall in stream 50 yd E. of Kentallen railway station (contact-altered). Anal. I. D. Muir.
2. Oniçh shore, 400 yd W. by S. of church (S 15376). Anal. B. Lightfoot.
3. Three hundred yards above path S.W. of Sgòrr a' Choise (contact-altered, S 15379, 15380). Anal. B. Lightfoot.
4. Dalnatrat, near Duror station. Supplied by Stewarts and Lloyds, Ltd.
5. Hillslope, 200 yd N.E. of Portnacroish (Appin station). Anal. B. Lightfoot.
6. Dalnatrat, near Duror station. Supplied by Steetley Lime and Basic Co., Ltd.
7. Marble Quarry, pathside, River Laroch, 660 yd S. of Laroch Bridge, Ballachulish. The full analysis by A. Muir and H. G. M. Hardie (1956, p. 20) shows Na_2O 1·95, K_2O 1·00.
8. Tributary of River Laroch, 660 yd S. 23°W. of Laroch Bridge, Ballachulish.
9. East of Duror railway station.
   Pure dolomite is quoted for comparison.

Analyses of Xenolith and of Contaminated and Normal Ballachulish Quartz-Diorite

	A	B	C	D	E	F
SiO_2	54·73	59·24	62·51	59·81	59·11	51·61
Al_2O_3	7·42	20·80	19·10	16·61	17·85	2·18
Fe_2O_3	1·71	0·29	0·65	1·50	1·78	1·04
FeO	5·03	0·99	0·41	2·80	3·24	9·28
MgO	8·11	1·20	0·23	2·49	3·85	11·29
CaO	18·32	7·13	2·01	3·20	5·05	22·86
Na_2O	2·35	7·47	2·18	3·49	4·10	0·43
K_2O	1·19	0·85	11·47	7·92	3·06	0·07
Etc.	1·05	2·22	1·50	2·05	1·66	1·09
Total	99·91	100·19	100·06	99·87	99·70	99·85

Analyses by I. D. Muir (1953a).

A. Xenolith of Appin Limestone transformed through immersion in Ballachulish quartz-diorite (see E. below). The specimen was taken 50 yd from **1** of previous Table.
B. Plagioclase zone enveloping **A,** and 1-2 inches thick.
C. Potash syenite zone enveloping **B,** 3 inches.
D. Augite-syenite zone enveloping **C,** a few inches.
E. Quartz-diorite of Ballachulish Pluton unmodified by Appin Limestone.
F. Diopside from **D.**

The contact-metamorphism does not notably increase the coarseness of texture of the altered limestone, but produces a grey tint in it which is often associated with an extremely rough manner of weathering. The grey shade is due to finely disseminated minute black pseudomorphs after forsterite. The rough weathering, as Teall has shown in a cognate case, depends upon the presence of residual dolomite side by side with calcite ; brucite is represented on the roughened surface by very small pits occurring indifferently in the dolomitic excrescences and the calcitic hollows. Isolated little rounded crystals of forsterite, Mg_2SiO_4, often more or less altered to chlorite or serpentine giving very low polarisation tints (S 13932), are easily identified under the microscope. The brucite appears as colourless and transparent spots of slightly larger size, which between crossed nicols break up into aggregates of more or less wavy, parallel scales with a moderate birefringence (S 13930). Obviously this scaly mineral is a secondary product, and its recognition as brucite is based upon a comparison with slides described by Teall (S 9208) ; no doubt the brucite, $Mg(OH)_2$, replaces periclase, MgO, the crystal form of which is sometimes suggested by the shape of the transparent spots.

Thus the Appin Limestone in this exposure, and also east of Glen Creran (Section F, chap. vi), illustrates the phenomenon of *dedolomitisation* in a rock in which the silica : magnesia ratio is lower than that required to yield tremolite ; and such is often the case with the Appin Limestone. Anal. 3 is of a grey specimen from the contact zone. It shows only slight dedolomitisation, because it contains so little silica that the amount of forsterite formed has been but trivial, while the more advanced change of dolomite to periclase does not seem to have taken place.

Various names have been given to dedolomitised marbles with the characters described above. Marbles consisting of calcite and serpentine, in most cases apparently derived from forsterite, are known as ophicalcites. Marbles, on the other hand, consisting of calcite and brucite are known either as pencatites or predazzites. Harker, in his account of the dedolomitised limestones of Skye (1904, p. 150), states that " it is most in accordance with the original usage to employ the name pencatite for an aggregate of calcite and brucite in equal *molecular proportions*, *i.e.* with the percentage composition of 63·3 calcite to 36·7 brucite, reserving the name predazzite for varieties richer in calcite."

A special study has been undertaken by Muir of xenoliths of Appin Limestone immersed in the quartz-diorite of the Ballachulish Pluton (1953a). The locality is in a stream 50 yards south of Kentallen railway station, 10 yards in from the pluton's margin and 150 yards from the coast. The xenoliths are pale green slabs, up to 3 feet in diameter and 3 inches in thickness (Anal. A, Table 4). They are bordered externally by successive distinctive zones (Anals. B-D) due to contamination of the surrounding quartz-diorite (Anal. E). Anal. 1, shown above, is from an Appin Limestone outcrop 50 yards downstream. Unfortunately the junction of this band with the quartz-diorite is not exposed.

Muir assumes that the xenoliths (Anal. A) had originally the same composition as the *in situ* limestone (Anal. 1). This seems uncertain since the xenoliths might quite possibly have been derived from some portion of the formation with a different composition, such as, for instance, that shown in Anal. 7 with its Na_2O 1·95 and K_2O 1·00. Be this as it may, Muir's main points seem firmly established. Early crystallisation of diopside and plagioclase within (Anal. A) and about (Anal. B) the xenolith have led to enrichment of the succeeding zones (Anals. C, D) of the quartz-diorite (Anal. E) in potash felspar, some residual, some refugee. We are furnished with a good example of what D. L. Reynolds would call a potash front.

Leven, Binnein, Eilde and Reservoir Schists.—The Leven and older mica-schists are sufficiently alike to be taken together in this account. The Leven Schists enter the aureoles of the Ben Nevis, Mullach nan Coirean, Ballachulish, Fault-Intrusion of Glen Coe, and Cruachan " Granites " ; while the Binnein and Eilde Schists are affected by the Fault-Intrusion of Glen Coe ; and the Reservoir Schists by the Moor of Rannoch " Granite ". All the slices quoted below come from the Leven Schists unless otherwise stated.

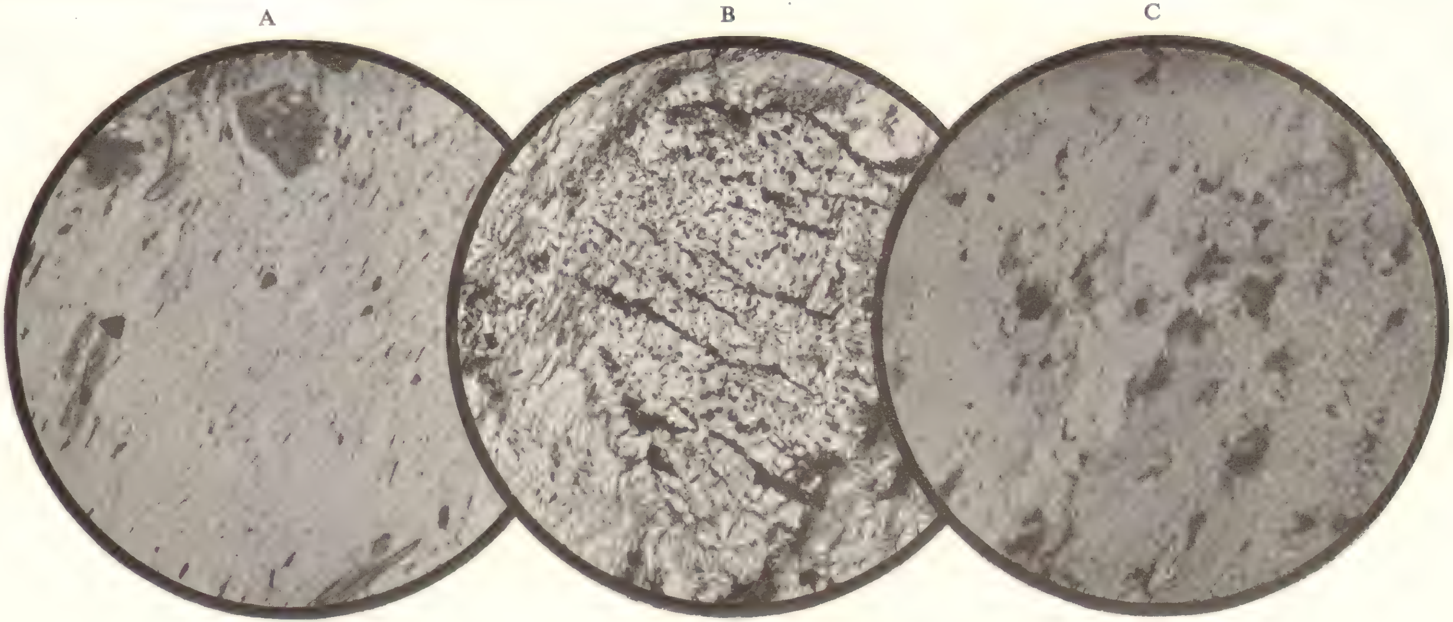
The Leven Schists, it will be remembered, are widely developed in the chlorite, biotite and garnet zones of regional metamorphism. A characteristic type is a grey phyllite or mica-schist, carrying small porphyroblasts of brown, highly pleochroic biotite, and much less frequent garnet, in a base of muscovite, quartz, and alkali-felspar, the last-named often in very small amount (Pl. XIIA). Irregular grains of iron ore are always present, and epidote is often a conspicuous accessory (S 11618) ; tourmaline and zircon occur as very minor constituents. In the banded group, near the margin of the Glen Coe Quartzite, there are fine-grained seams of a dark tint, probably due to disseminated carbon. Similar dark bands occur also at the quartzite margins of the Binnein and Eilde Schists (S 12925).

Green chlorite has frequently arisen through the weathering both of biotite and of garnet ; and sometimes it plays an important rôle as a primary mineral along with the muscovite of the base (S 11619). Biotite commonly occurs in the groundmass of the Binnein and Eilde Schists (S 12362). The alkali-felspar generally forms irregular water-clear grains associated with the quartz, which at times it almost equals in amount. In other cases the felspar has segregated into small round crystals, including quartz in poikilitic fashion (S 12361). Such crystals sometimes show indications of the microcline type of twinning, in which case they are probably orthoclase, including microcline. The occurrence of alkali-felspar with this habit, as the result of regional metamorphism, is not at all infrequent.

Most of the rocks of the Leven Schists, outside the " granite " aureoles, have a very perfect wavy foliation, owing to the regular orientation of the muscovite and to the lenticular arrangement of the quartz granules in between. This foliation may make any angle with the bedding (S 11620), and may itself be crossed by a later strain-slip cleavage. The arrangement of the biotite porphyroblasts is distinctly less regular than that of the muscovite flakes in the groundmass. While marked schistosity is so common, it is not the invariable rule. Occasionally a quartzose band occurs consisting for the most part of small, evenly distributed grains of quartz and flakes of mica, with so little orientation that there is an approach to the " cobble-structure " more characteristic of hornfelses.

In the Leven Schists, *near the various* " *granite* " *masses*, both andalusite and cordierite are of widespread occurrence ; while corundum has been found in certain xenoliths of Eilde Schists (S 11519). Sillimanite has only been detected in a couple of xenoliths (S 10309, 10310) from the An t-Sròn " Granite " (Fault-Intrusion of Glen Coe). It is associated with corundum, and the second of the two slides mentioned is a very typical example of sillimanite-cordierite-corundum-hornfels rich in almost opaque green spinel.

The andalusite is very easily recognised in thin slices owing to its high refractive index ; very occasionally, too, it shows strong pleochroism (S 15450). In



PHOTOMICROGRAPHS OF LEVEN SCHISTS BEFORE AND AFTER CONTACT-ALTERATION. × 21 DIA.

A. Not contact-altered, Glen Leac na Muidhe (S 11618). Porphyroblasts of biotite, garnet and magnetite in well foliated base of muscovite, quartz and magnetite.

B. Slightly contact-altered, ¾ mile from Cruachan ''Granite,'' Glen Etive district (S 8270). Pseudomorph, largely of cordierite and magnetite, after garnet in well foliated base of muscovite, quartz and magnetite.

C. Completely reconstructed to cordierite-andalusite-hornfels, near Ben Nevis '' Granite,'' Aonach Beag (S 13837). Cordierite, pale, N.W. half ; andalusite, darker, S.E. half ; biotite and magnetite, dark to black.

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form its crystals are, as a rule, intensely irregular, but all the same they not infrequently possess rectangular boundaries parallel to a prismatic cleavage. Although the mineral can rarely be determined in the field, it is responsible for many of the excrescences which weather out on the surface of the hornfelses (S 11484) ; there are, moreover, capital exposures, just at the margin of the map, at the edge of the Ben Nevis " Granite," north of Aonach Mòr, where certain bedding surfaces of the Leven Schists are covered with prominent little prisms of andalusite about ⅜ inch long (S 13921) ; very conspicuous crystals of the mineral are also exposed in Reservoir Schists in the bed of the river Leven, a third of a mile west of the Moor of Rannoch " Granite". It is generally admitted that the presence of andalusite in an aureole, in place of sillimanite, shows that the granite responsible for the metamorphism was not excessively hot.

Cordierite is often more conspicuous in the field than under the microscope. The mineral tends to occur in spots, sometimes slightly elongated along the foliation, and these weather freely, leaving a pitted surface. Glen Nevis affords a magnificent series of spotted cordierite-hornfelses belonging to the Leven Schist Group.

When examined under the microscope the cordierite is not easy to detect until a considerable familiarity with the mineral has been obtained. It never builds regular crystals, and its refractive index and birefringence make it closely resemble quartz and the felspars. It sometimes occurs in bundles of crystals with subparallel orientation (S 13921), and it also frequently shows very complicated twinning (S 13837), so that between crossed nicols it attracts attention by a patchy uncertain illumination. In other cases where the crystals extinguish uniformly, their comparatively large size may help to distinguish them from associated grains of quartz and felspar. Cordierite too, in the rocks under consideration, has a distinct tendency to enclose rather numerous small crystals of magnetite, and its presence is often betrayed in consequence. As confirmatory tests we may rely upon the straight extinction referred to the cleavage, the mode of weathering, the wide-angled biaxial figure, and above all the faint, often very faint, yellow pleochroic halos round inclusions of zircon.

Other mineral changes go hand in hand with the production of the andalusite and cordierite. They are the destruction of muscovite, chlorite, garnet, and quartz, and the building up of felspar, in the main of alkali composition. Biotite is probably decomposed to a considerable extent, too, in many cases ; but this is often merely a matter of inference (see below), for recrystallised, or freshly synthesised, biotite is a characteristic constituent of most of the hornfelses. In the contact-metamorphism of the igneous rocks, to be discussed in a later section of this chapter, biotite has been synthesised very freely indeed. The completeness of the destruction of the muscovite depends upon the conditions of the metamorphism : round the Fault-Intrusion of Glen Coe there seems to have been a regeneration of muscovite at a late stage, in a manner suggesting pneumatolysis ; it will be remembered that permeation phenomena are well marked in this same zone. The destruction of quartz is a by-process, as it were, of the other reactions ; such quartz as is not required to help build up the andalusite and cordierite merely recrystallises without change. Magnetite is liberated in some of the reactions, such as the destruction of the garnets, and is perhaps absorbed in other reactions, such as the recrystallisation or synthesis of biotite. It is more idiomorphic in the hornfelses than in the original schists.

The destruction of muscovite and chlorite leads to the *elimination of the volatile constituent water*, and so, as has been pointed out in connection with the alteration of the limestones, has much in common with the decomposition of calcite and dolomite. The replacement of garnet is of course on a different footing; like the disappearance of quartz in so many of these rocks it may perhaps be a secondary reaction involved in the destruction of the muscovite.

There can be no reasonable doubt that andalusite has arisen according to the following equation :

$$\underset{\text{Muscovite}}{H_2KAl_3(SiO_4)_3}+\underset{\text{Quartz}}{SiO_2}=\underset{\text{Andalusite}}{Al_2SiO_5}+\underset{\text{Orthoclase}}{KAlSi_3O_8}+\underset{\text{Water}}{H_2O}$$

The association of andalusite with alkali-felspar required by this equation is of extremely common occurrence in the Leven Schist hornfelses. A simple example from Beinn Ceitlein, east of Glen Etive, has thin dark layers rich in biotite, separated by quartzose layers, in which granules of quartz occur in a matrix made up of small grains of alkali-felspar and large exceedingly irregular crystals of andalusite, the latter in part altered to shimmer aggregates (S 11484). A specimen from the margin of the Ben Nevis " Granite " illustrates the alteration of a less siliceous rock where all the quartz has been required to carry through the reaction. It consists of layers, some mainly composed of andalusite and others of cordierite (Pl. XII C). Biotite in small, oblong crystals is fairly abundant, and has no parallel orientation, but instead is collected into nests and layers for the most part attached to crystals of iron oxide. The central portions of the andalusite crystals are sometimes solid, but the outer portions are built up of an infinite number of minute parallel rods, and between these rods a high power objective reveals alkali-felspar with a refractive index lower than balsam.

While most of the felspar in these hornfelses is alkali-felspar, instances are known in which andesine occurs. This is the case in a specimen taken, like the last, from near the border of the Ben Nevis " Granite ". Andalusite and cordierite are commingled here instead of being in separate layers (S 13921). The matrix between the various crystals of these two minerals carries abundant biotite, with more or less parallel orientation, associated with granular andesine ; there is also a small amount of muscovite present. The andesine is distinguished from cordierite through a tendency to central decomposition and a faint zonal structure. Its lowest refractive index, by comparison with balsam, appears to be rather higher than the lowest of quartz, while a grain examined in convergent light proved to be optically neutral ; it may be taken as andesine with 30-40 per cent. anorthite, and it has probably derived its lime from epidote in the original schist.

In a specimen of Reservoir Schist, 300 yards from the edge of the Moor of Rannoch " Granite " (S 11529), there is much andalusite, but so little felspar that one is tempted to suppose that alkali may have been used up in regenerating biotite from chlorite, or in some such change. Muscovite and quartz are both still well represented in this rock.

The development of corundum may be taken as a result of the decomposition of muscovite in the absence of sufficient quartz to yield andalusite.

$$\underset{\text{Muscovite}}{H_2KAl_3(SiO_4)_3}=\underset{\text{Orthoclase}}{KAlSi_3O_8}+\underset{\text{Corundum}}{Al_2O_3}+\underset{\text{Water}}{H_2O}$$

Corundum was first found in the West Highlands by Teall among the hornfelses bordering the Cruachan " Granite " in Sheet 45, Geol. In the district at present dealt with the mineral is apparently restricted to xenoliths. It is quite common in enclosures of Eilde Schist in the Fault-Intrusion of Glen Coe (S 11519).

It is impossible to write down equations for the production of cordierite $(Mg,Fe)_4Al_4Si_5O_{18}$ owing to the indefiniteness of its own composition and of those of the minerals from which it must have derived its magnesia and iron. Three possible sources of magnesia and iron are present in the unhornfelsed schists, to wit, biotite, chlorite, and garnet. Writing biotite $(K,H)_2(Mg,Fe)_2(Al,Fe)_2(SiO_4)_3$ it appears that, making allowance for the alumina and silica which will be retained by the potash to yield felspar, additional alumina and silica will be required to convert all its magnesia and iron to cordierite ; these constituents will be derived from reaction with muscovite and quartz respectively. The same two minerals will also be called upon to help in the production of cordierite from chlorite $H_{40}(Fe,Mg)_{23}Al_{14}Si_{13}O_{90}$. As for garnet, without a local analysis it is not worth while writing down a formula.

Turning to the slides we find cordierite occurring in two distinct ways. It either forms part, or nearly the whole, of certain pseudomorphs after chlorite (or perhaps biotite) and garnet, or else it builds aggregates, or spots, and other independent growths. In the pseudomorphs which appear to be after chlorite, the cordierite is found forming the termination of biotite porphyroblasts, and enclosing lines of magnetite which obviously mark the former position of biotite cleavages. It seems probable in such instances that first the biotite has weathered terminally yielding chlorite with the usual discharge of iron oxides, and then this chlorite has been itself metamorphosed to cordierite. The change is well illustrated in a series of specimens (S 8269-8271) from ¾ mile north of the Cruachan " Granite," and in a slide from Glen Nevis (S 15447). The replacement of garnet by biotite, cordierite, and magnetite, with, in certain cases, muscovite and quartz, is represented in the slides just noted from the north of the Cruachan " Granite " (Pl. XII B). It is also shown in a specimen from the road-cutting, ½ mile east of the Ballachulish " Granite " (S 15368), and in another from the Glen Nevis gorge, ¼ mile from the Ben Nevis " Granite " (S 15870).

It is probable that the garnets, like the biotites, were in part changed to chlorite before the intrusion of the granites. At the same time it is fairly certain that garnets not previously chloritised have also been pseudomorphed, since only one slide in the collection (S 11785) shows a highly altered rock retaining any garnet at all ; and, in this case even, the garnet occurs as mere remnants in the heart of a cordierite pseudomorph.

That cordierite has sometimes derived its ferromagnesian constituents at the expense of biotite is inferred because neither chlorite nor garnet seems to be present in sufficient quantity in the unmodified Leven Schists to account for the great abundance of cordierite developed in the hornfelses.

Before passing on to consider the somewhat aberrant types from the neighbourhood of the Fault-Intrusion of Glen Coe, a few words may be said about the texture of the rocks already dealt with.

A remarkable amount of contact-alteration may take place without deleting the original schistose texture (*cf.* Barrow 1909, p. 84 ; Flett and Barrow 1910, p. 64). Andalusite is sometimes abundantly developed in a muscovite-biotite-gneiss or schist in which the micas retain their original orientation with great perfection (S 11529, Reservoir Schist). Cordierite spots in their earlier stages are but meshworks, including mica flakes and quartz lenticles still evenly arranged (S 15444).

In advanced stages, however, texture is revolutionised : foliation can scarcely be recognised under the microscope ; all muscovite is gone ; biotite is in clusters of oblong crystals round grains of magnetite (S 13837), or in isolated flakes in a felspathic ground between crystals of the now dominant andalusite and cordierite (S 13921) ; where andalusite and biotite occur in small amount the resulting rock has a well-defined " cobble-structure " designed in quartz, felspar, and cordierite, the latter accompanied by the usual small crystals of magnetite (S 15445, 15446).

The Fault-Intrusion's contact-metamorphism seems often pneumatolytic with muscovite an important end product. In an Eilde Schist specimen (S 15363) from near the " granite " margin, in the tributary valley entering Allt Coire Mhorair, north of Glen Coe, very little quartz is left, and it is in an obviously highly corroded condition, and surrounded by alkali-felspar. Most of the rock consists of muscovite, with a tendency to bushy growth, and associated biotite. Porphyroblasts of the last-named are in part replaced by muscovite, especially at their margins. Irregular crystals of andalusite, with late-formed quartz moulded upon it, are also present in the closest possible conjunction with the muscovite.

In a Leven Schist specimen (S 11622) taken by Maufe, at 100 yards from the An t-Sròn " Granite " of Glen Coe, the original foliation is merely indicated by a certain elongation of the quartz grains ; the latter lie in a recrystallised matrix of cloudy alkali-felspar and unorientated muscovite. The porphyroblasts of biotite are easily recognised, but their outer portions are replaced by muscovite, and their kernels, apparently as a result of recent weathering, by chlorite. The muscovite throughout has a brush-like tendency of growth.

At two feet from the same " granite," further south, at the head of Gleann Fhaolain, the Leven Schist has entirely lost its schistose structure (S 11626). There is a considerable amount of quartz, but this has all recrystallised, and occurs in interspaces, including idiomorphic crystals of cloudy alkali-felspar and certain oblong pseudomorphs ; the latter are probably after cordierite, and are occupied by plumose muscovite, either alone or associated with yellow chloritic pinite (*cf.* Flett 1907, pl. vi, fig. 1). Muscovite of a similar habit occurs in abundance in the felspathic portions of the rock, and in both positions appears to be a product of the contact-alteration. It therefore seems probable that cordierite, developed in earlier stages of the metamorphism, has been destroyed in later stages as a result of pneumatolysis. Biotite occurs in abundant little, stumpy, new-formed crystals, and the original porphyroblasts of this mineral can also be recognised, now largely replaced by muscovite.

Appin Phyllites.—Unaltered rocks of the Appin Phyllites have not been specially studied microscopically ; but the group is of interest as yielding very fine examples of spotted cordierite-hornfels on both sides of the Ballachulish " Granite ". This type of alteration extends for about a quarter of a mile from the " granite," and is well exhibited near Kentallen on the west and in the valley of Allt Giùbhsachain on the east.

As specimens of these conspicuous dark-spotted hornfelses can be very readily obtained by any one visiting Kentallen, a detailed description of a typical example is here appended (S 14300). The spotting is very well seen on the weathered surface. The spots are dark and spherical and make up the bulk of the rock, while the interspaces are pale and slightly pink. Under the microscope the spots are best perceived by reflected light, for then the interspaces are pink, while the spots remain dark owing to their transparency. By transmitted light the spotting is seen to have very little influence on the general " cobble-structure " of the rock, which is that of a quite unfoliated granulite composed in the main of very abundant small grains of quartz, twinned albite-oligoclase (and probably some orthoclase), and small oblong crystals of brown biotite ; there are also larger poikilitic muscovites. The spotting is determined by the presence of cordierite crystals, measuring $\frac{1}{8}$ inch across, which constitute the basis of the spots and enclose the minerals mentioned above in poikilitic fashion. The cordierite has a higher refractive index than quartz, shows yellow pleochroic halos round zircon inclusions, has a strong tendency to marginal decomposition along its cleavages, and is sometimes wholly replaced by a shimmer aggregate of muscovite. Whether fresh or decomposed itself, the minerals it encloses are wonderfully unaltered, whereas in the interspaces between the spots the biotites are highly weathered with liberation of iron oxide, and the felspars are often cloudy. It is this susceptibility of the minerals to decomposition where not enclosed in the cordierite which makes the matrix of the spots pale in the hand specimen as compared with the spots themselves. Notwithstanding this, on an exposed surface the spots disintegrate more quickly than the matrix.

In regard to the origin of these spots it is certain that they are new segregation structures developed during the contact-metamorphism. They cannot be ascribed to the former presence of garnet, for the Appin Phyllites here lie entirely outside the garnet zone.

Ballachulish Slates.—Rocks of the Ballachulish Slate group at a distance from the " granites" have a very fine crystallisation, much finer than that of the Leven Schists on the one side of them or the Appin Phyllites on the other. This denotes a selective regional metamorphism which is probably connected with the large amount of finely disseminated carbon present in the group. Garnet has been reported only from Glen Coe and Coire Mhorair (pp. 75, 80). Big cubes of pyrites, however, are a common feature, and Harker (1889) has described composite eyes in Ballachulish Slate with pyrites centres and quartz at both extremities due to pressure acting upon the slates after the formation of the pyrites —but examples of this phenomenon are very rare, at any rate in the main quarry.

The general micaceous base is too fine for profitable microscopic investigation with ordinary powers. It encloses numerous minute lenticles of quartz (S 15383A) and a few of chlorite. In the latter the chlorite occurs as single crystals, each one with rounded outlines and with the cleavage making a high angle to its greater length.

The group comes within the range of the Ben Nevis, Mullach nan Coirean and Ballachulish " Granites," and gives splendid examples of spotted cordierite-hornfelses. In these the foliation is lost, and large poikilitic crystals of cordierite are very abundant (S 14393). Quartz in small grains and a pale biotite in little flakes are the other main constituents. Muscovite, biotite and, sometimes, tourmaline build poikilitic little porphyroblasts ; while iron oxide or another nearly opaque mineral is present in small grains. Much of the carbon is retained, and iron sulphide has recrystallised, moulded on quartz (S 14392).

In the 1916 edition of this memoir the slide last mentioned (which comes from the aureole of the Ballachulish " Granite ") was stated to show recrystallisation of pyrites. This must be corrected, for Neumann has demonstrated that pyrites, FeS_2, in the Ballachulish aureole has been decomposed to yield pyrrhotite Fe_nS_{n+1} and sulphur (1950). The pyrrhotite has crystallised in aggregates replacing the pyrites cubes, and the surplus sulphur has disappeared. Neumann has further shown that this change occurs well beyond the limits of other signs of alteration. For instance, he found all the pyrites of the North Ballachulish roadside slate quarry to have been converted. Neumann saw that it was impossible to assign an exact temperature for the dissociation, since this depends upon facility of removal of the liberated sulphur ; but he pointed out that the equilibrium sulphur-vapour-pressure of pyrites at 600°C is only 20 mm of mercury.

Pyrrhotite is decomposed by acids with liberation of sulphuretted hydrogen. Accordingly, Neumann's discovery solves two long-standing puzzles : the first is the weathering out of the iron sulphide crystals in the North Ballachulish slate quarry in contrast with their stability in the main quarry south of Loch Leven ; and the second is the smell of sulphuretted hydrogen which the Ballachulish Limestone emits when broken in its outcrops south of the Ballachulish Pluton. As already pointed out (p. 240) this phenomenon extends for a mile beyond the limit of the Ballachulish aureole as drawn in Fig. 39.

In an interesting slide of Ballachulish Slate hornfels from the Stob Bàn ridge, in the Mullach nan Coirean aureole, cordierite is seen springing in crystal aggregates from layers of carbon, marking the course of strain-slip cleavages in the original slate (S 15371). The rest of the slide is made up of flakes of pale biotite or phlogopite, with very imperfect orientation, and accompanied by numberless minute granules of green spinel. The latter often marks out the course of an early cleavage or foliation which has later been crossed by the strain-slip cleavage already referred to. Last of all, of course, came the contact-alteration.

Reservoir Flags.—The only psammitic group which we shall discuss here is that of the Reservoir Flags. These rocks consist for the most part of fine-grained quartzo-felspathic gneisses carrying abundant muscovite and biotite, and are thoroughly well banded owing to the alternation of more and less micaceous layers. The foliation, as indicated by the orientation of the micas, is more regular than in the pelitic schists, and usually runs parallel to the banding. The felspar, which is often as abundant as the quartz, is alkali. Garnet, epidote, sphene, iron ore, and zircon occur as accessories. The rocks recall many descriptions, published by Barrow (1904) and others, of Central Highland " Moine " gneisses.

The Reservoir Flags come within the aureole of the Moor of Rannoch " Granite " for a considerable distance, and there exhibit changes quite comparable with those of the pelitic rocks. Andalusite develops (S 11530, 15367), and the biotite recrystallises in small unorientated flakes. Only two slides have been cut from these hornfelsed flags, otherwise it is tolerably certain that cordierite would have been found as well as andalusite.

Quartz Xenoliths.—Muir has described important reactions between quartz xenoliths and the Ballachulish quartz-diorite (1953b). His specimens came from the mostly northerly of the roadside " granite " quarries near Kentallen. The xenoliths are a few inches in diameter, and are margined by ferromagnesian coronas up to three-quarters of an inch thick. The inner part of an individual corona may be rich in pale green augite (Anals. I, A, Table 5) ; while the outer, much wider portion is mostly composed of hornblende (Anals. II, B). For some little distance beyond a corona the quartz-diorite is still notably modified but in reciprocal fashion with strong development of quartz (Anal. III). Inside a corona there may be considerable felspathic crystallisation rich in orthoclase.

Muir discusses the evidence in detail and supplies a valuable review of more or less similar occurrences elsewhere in the world. According to appearances in such cases (Bailey and McCallien 1956, p. 468) it would seem that silica, dissolved from xenoliths and diffusing outwards, has led to ferromagnesian precipitation, giving augite at first, often followed at lower temperatures by hornblende. Felspathic constituents have meanwhile been free to migrate inwards until finally checked by falling temperature. There is some slight experimental support for this interpretation since the eutectic melting-point of diopside-and-silica is 1362°C, whereas the corresponding values for diopside-and-anorthite and diopside-and-albite are 1270°C and 1085°C respectively (Bowen 1928, pp. 26, 48, 49). That the ferromagnesian precipitation should start with augite rather than hornblende in the case of the Ballachulish quartz-diorite is not surprising considering the chemical composition of the rock. Also Walker has noted that " in a few sections one or two small crystals of pyroxene were observed enclosed in hornblende " (1924, p. 550).

E. B. B.

TABLE 5

Analyses illustrating Reactions between Quartz Xenoliths and Ballachulish Quartz-Diorite

	I	A	II	B	III	IV	C
SiO_2	59·94	49·71	59·43	46·30	62·53	59·11	45·15
Al_2O_3	5·04	2·85	5·54	8·60	16·49	17·85	8·10
Fe_2O_3	2·00	2·76	4·63	2·78	1·82	1·78	2·10
FeO	4·97	7·45	7·08	10·16	2·99	3·24	12·97
MgO	8·30	13·35	7·89	13·15	2·80	3·85	13·30
CaO	14·72	22·36	9·05	13·55	4·78	5·05	12·84
Na_2O	1·87	0·60	1·65	1·05	4·17	4·10	0·66
K_2O	0·14	0·04	0·58	0·48	2·12	3·06	0·32
Etc.	2·52	1·13	4·55	3·82	2·53	1·66	4·10
Total	99·50	100·25	100·40	99·89	100·23	99·70	99·54

All analyses by I. D. Muir.

I. Augite-rich inner zone of corona.
A. Augite from **I.**
II. Hornblende-rich outer zone of corona.
B. Hornblende from **II.**
III. Modified **IV**, 2 inches outside corona.
IV. Normal Ballachulish quartz-diorite.
C. Hornblende from **IV.**

CONTACT-ALTERED LAVAS OF GLEN COE AND BEN NEVIS

We may begin by reproducing the gist of an account of the contact-alteration of the hornblende-andesites and rhyolites of Glen Coe, which Kynaston had furnished before leaving the Survey (Sum. Prog. 1901, p. 82).

Hornblende-Andesites.—Excellent sections of the contact between the Cruachan " Granite " and the hornblende-andesites of Glen Coe may be seen : at the west end of the Meall a' Bhùiridh ridge (Sheet 54, Geol. ; see Fig. 29, p. 164) ; on the ridge running due north from the summit of Clach Leathad ; and on the west side of the corrie at the head of Càm Ghleann. Contact-alteration of the andesites may be recognised in the field by gradual replacement of the normal dark-grey or almost black colour of these rocks by pale grey, and concurrent development of a fine holocrystalline texture in their groundmass. The altered lavas also lose their sharp angular fracture. Such changes do not extend for more than about 300 yards from the " granite " contact.

A large number of micro-sections of the altered andesites have been examined. The brown idiomorphic hornblende appears to be the first mineral to be attacked. It is replaced by clusters of small biotite flakes, usually associated with aggregates of granular green hornblende and magnetite (S 9163, 9174). At first the form of the original crystal is clearly seen, but in the later stages it is completely lost. Frequently the replacing aggregate consists almost entirely of grains of green hornblende, though in the pyroxene-bearing varieties north of Clach Leathad the brown hornblende is replaced almost entirely by biotite, with a little magnetite. In the commencing stages of the alteration portions of the original hornblende may be seen surrounded by a dense cluster of small biotite flakes, the outer margin of which retains the characteristic form of the hornblende crystal (S 9179). The felspar phenocrysts are usually marked by a peculiar cloudiness, also observed in the altered andesites of the Cheviot district and other places ; but they show a marked stability, and sometimes appear to maintain their individuality even at the actual contact (S 9169). The microlites of the groundmass become indistinct, and gradually the entire groundmass is replaced by a clear granular mosaic, consisting probably largely of felspar with some quartz (S 9171, 9174). At times a relatively coarse aggregate of clear micropoikilitic felspar is seen in the more advanced stages, as in (S 9176). This last is a junction specimen, where a profusion of small biotite flakes, often in aggregates, and frequently accompanied by green hornblende and granules of magnetite, lies scattered throughout. The green hornblende is sometimes in excess of the biotite (S 9177-8). Grains of sphene occur at the actual contact (S 9176). The pale greenish augite present on the ridge north of Clach Leathad may be replaced by a pale green hornblende, but it shows far more stability than the phenocrysts of brown hornblende (S 9179). At the contact the " granite " is sometimes fairly coarse and of an acid type. It often encloses small fragments of andesite (S 9169).

Rhyolites.—Several well-marked contacts between the rhyolitic rocks of Glen Coe and the Cruachan " Granite " may be seen on the west slopes of Sròn na Crèise, not named in Fig. 29 but just north of Stob Ghlas Choire and east of the River Etive. On approach to the " granite " the rhyolites entirely lose their normal compact and flinty texture, assume a pale greyish or pale pinkish colour, and somewhat resemble fine-grained quartzo-felspathic granulitic rocks. A specimen of one of them shows a peculiar appearance under the microscope (S 9735). It looks as if originally a spherulitic rhyolite, owing to the presence of numerous circular and oval-shaped patches, and elongated bands with rounded ends ; but these portions now show no spherulitic texture, instead breaking up into a relatively coarse microcrystalline granular aggregate. The surrounds are usually considerably finer grained. The aspect between crossed nicols is that of a curious intermixture of relatively coarse and fine-grained areas.

Another specimen (S 9736), a few feet from the " granite," shows some remains of felspar phenocrysts and patches of secondary flakes of chlorite and pale green biotite ; but the greater part of the rock is a fine granulitic quartzo-felspathic aggregate with an unusual micropoikilitic structure. H. K.

Lavas in general.—Further examination of the material, now greatly extended, has suggested that the contact-alteration affected lavas sometimes already much weathered. But before considering this point it will be well to show how the continuation of the aureole about the Cruachan " Granite " has been followed through the portion of the district not examined by Kynaston.

South-east of Lairig Gartain, Grabham collected numerous striking specimens which illustrate the contact-alteration of the lavas, both north (S 12462, 12464-7, 12510-2) and south (S 12756-12761, 12764-6) of the " granite " there exposed ; while Maufe has investigated the same subject on the other side of the valley from Buachaille Etive Beag to Dalness (S 11602, 11605-7, 12437-8, 12441-6, 13768-9), and has shown that contact-alteration is recognisable at about three-quarters of a mile from the " granite " margin (S 11605-6).

Clough has found, as might be expected, that all the lavas lying south of the River Etive in the Dalness district fall within the contact zone (S 11455, 11487-11490).

Similar contact phenomena have been recorded by Maufe from Ben Nevis (S 8825, 13734, 13743, 14022-4, 14422).

It has already been mentioned that there is reason to believe that the contact-alteration was sometimes superinduced upon an earlier decomposition, probably due in the main to weathering. This circumstance is fairly clear in many cases where the new hornblende and biotite have been formed along the courses of cracks—presumably previously occupied by such minerals as calcite, chlorite, and perhaps epidote (S 9174, 9179, 12757). In like manner tremolite has replaced earlier amygdale minerals (S 11456). Clouding of felspar will be discussed later (p. 259).

The indications of weathering outlined above recall those upon which Harker and Marr (1891) laid stress in describing the contact-altered andesites near the Shap Granite of the north of England. Moreover, the conditions which reigned during contact-alteration were similar in both cases, leading to an abundant formation of biotite and hornblende—the latter resulting, as Harker and Marr pointed out, wherever a source of lime was available, such as calcite or epidote. Potash, an essential constituent of biotite, seems to have been comparatively mobile in the heated rocks. Magnetite, as, for instance, the magnetite of the resorption borders round original hornblendes and biotites, has often helped to locate growing clusters of biotite, and has been eventually more or less completely digested. It is, of course, probable that the proximity of unstable minerals, such as chlorite and calcite, has powerfully influenced comparatively stable minerals, such as augite and hornblende, and in a good many cases led to their destruction.

The various minerals which have resulted from contact-alteration have tended to develop in all directions. As a result the altered rocks assume somewhat granulitic and poikilitic characters. This feature is best illustrated in the base of altered glassy rocks, for the most part rhyolites (S 12756, 12758). In the andesites the lath-structure of the original is strikingly modified in the same sense, but never obliterated (S 9730-1, 12512). There can be considerable development of biotite and hornblende before this tendency towards a granulitic texture becomes in any way marked.

E. B. B.

CONTACT-ALTERED SEDIMENTS OF GLEN COE

Breccias.—At the junction between the hornblende-andesites and the underlying breccias at the west end of Meall a' Bhùiridh (Fig. 29, p. 164), some altered rocks occur which, though of an andesitic appearance, probably belong to the breccias rather than the andesites. They are rich in quartz grains and fragments of quartzose schist as well as andesite. The pieces of schist appear to be gradually losing their individuality ; their sharp outlines become indistinct, and under the microscope (S 9170) the fragments tend to merge into the surrounding rock. The main mass of the section examined consists in part of a mosaic of quartz and felspar throughout which are scattered numerous small flakes of secondary biotite, minute greenish grains (? hornblende), and magnetite, and in part of quartz grains in a fine brownish matrix. Other portions, again, break up into a mosaic of micropoikilitic felspar, in which the secondary minerals are embedded. Sometimes there is a marked parallel arrangement, and sometimes an appearance of brecciation (S 9173). In the less altered specimens the andesitic portions retain their original texture (S 9172).

The contact between the Cruachan " Granite " and the breccias is well seen at the head of Càm Ghleann and to the west beyond the hornblende-andesites of Stob Glas Choire (Sròn na Crèise). In the field the usual dark and almost compact matrix of these rocks becomes a pale-grey or sometimes pinkish colour ; and it feels sandy to the touch in the more weathered specimens, no doubt owing to the rock assuming a secondary granulitic texture. The microscope again shows (S 9733, 9734) that the distinction between fragments and groundmass has become much less clear than in the normal unaltered rocks, except where the fragments consist of andesite, or in rare cases of " granite " (S 9734). The groundmass would appear to have undergone reconstruction, and now constitutes a microcrystalline quartzo-felspathic mosaic, which may closely resemble in texture the included fragments. When these are felsitic, they are usually finer grained than the groundmass. Patches of small flakes of secondary biotite and some chlorite may also be seen scattered about, with here and there some original quartz grains and felspars.

Fine Sediments.—The sedimentary band intercalated in the andesites of Stob Glas Choire (Fig. 29, p. 164) shows considerable induration at a distance of about half a mile from the Cruachan " Granite ". The band consists of fine-grained dark shale interlaminated with more gritty portions. Its beds break just as easily across the lamination as parallel to it. Close to the " granite " considerably greater alteration may be observed, and portions of the rock have been converted into a fine-grained spotted hornfels, with minute dark spots on a paler background. A section under the microscope (S 9739) shows that these spots are roughly oval patches of minute, densely packed flakes of secondary biotite together with small grains of quartz. They tend to coalesce along certain bands which are slightly coarser than the rest of the rock. H. K.

Well-marked induration has been recorded by Kynaston in a band of purple shales which occurs on the east side of a gorge on the north-eastern slopes of An t-Sròn, on the south side of Glen Coe. The shale is adjacent, across the Boundary-Fault, to " Granite " of the Fault-Intrusion ; and its alteration is undoubtedly attributable to the same ; but the impressive phenomenon, here as elsewhere, is how little this intrusion has achieved in the way of contact-alteration inside, as compared with outside, the Cauldron-Subsidence.

CONTACT-ALTERED INTRUSIONS

Introduction.—The district furnishes several interesting examples of contact-alteration of intrusions. Maufe first detected this phenomenon in a dyke of the Etive Swarm cutting the Ben Cruachan " Granite " close to the margin of the Starav Granite, a quarter of a mile east of Glenceitlein cottage, Glen Etive. He ascribed the contact-alteration in this case to the effect of the Starav Granite, and other instances in confirmation have since been found. Maufe further showed that dykes of the Ben Nevis Swarm are altered by the Inner " Granite " of the same complex. In addition a few early dykes are known to be altered by the Main Fault-Intrusion of Glen Coe, others by the Cruachan " Granite ". Contact-alteration of plutonic intrusions, big or small, is generally less demonstrable ; but examples in the Early and Main Fault-Intrusions of Glen Coe, the Moor of Rannoch " Granite," the Glen Ure augite-diorite and the kentallenite of Kentallen are discussed below.

Dykes earlier than the Main Fault-Intrusion and the Cruachan " Granite ".—The thin north-east lamprophyre dyke (S 11523), noted on p. 196 as veined by the Fault-Intrusion in the permeation area north of Glen Coe, carries pseudomorphs composed of bladed aggregates of pale-green hornblende accompanied to a minor extent by brown biotite. Its neighbour (S 11524), also mentioned, is completely reconstructed into an augite-biotite-quartz-granulite. A comparably granulated lamprophyre (S 11575), with unknown field relations, has been collected 300 yd S.W. of the exit of Loch Achtriochtan. Here again contact-alteration must be referred to the Main Fault-Intrusion.

The porphyrite (S 12345) and felsite (S 12344), shown in Fig. 23 as contiguous dykes flanking a branch of the Boundary-Fault of the Glen Coe Cauldron north of Meall Dearg, have both suffered intense granulation at the hands of the Fault-Intrusion.

Another early felsite (S 11460-3), this time altered by the Cruachan " Granite," comes from Beinn Ceitlein, Glen Etive. It is remarkable for a rich development of minute flakes of muscovite and biotite, which are sometimes grouped along fluxion bands, or else margin reconstructed spherulites.

Certain altered dykes cutting the calc-silicate-hornfels south of Glen Ure were regarded by Kynaston as belonging to the hornblende-schist suite referred to on p. 69. They may, however, be pre-Cruachan-" Granite " forerunners of the Etive Swarm.

Dykes of the Etive Swarm.—A porphyrite dyke veined by the Meall Odhar Granite, 930 yd south-east of the southern lochan on Beinn Ceitlein, shows characteristically clouded felspars. Moreover, its groundmass is suspiciously coarse (S 11496).

There are only a few slides of dykes showing contact-alteration undoubtedly due to the Starav Granite. Two come from Allt Dochard in Sheet 45, Geol. Their felspars are to some extent clouded, and characteristic aggregates of brown biotite and green hornblende have been developed along with a very perfect granulitic texture (S 14182-3). This stream section is very interesting, for, as has already been pointed out, there can be no doubt that its numerous dykes are earlier than the closely adjacent Starav Granite, since they are freely cut by aplite veins. A suite of slides was accordingly prepared, and the general failure to detect clear evidence of contact-alteration in them confirms the view that fresh igneous rocks are not readily susceptible to conspicuous contact-alteration. The two cited above had been sheared before or during the heating process.

A very beautiful example of contact-alteration is afforded in Sheet 53 by a dyke exposed near the Starav Granite in the bed of Allt Ceitlein, a quarter of a mile E.S.E. of Glenceitlein cottage (S 13762). There is a suggestion here of previous albitisation, with slight introduction of soda. Another good example comes from across Glen Etive, from Allt nan Gaoirean, nearly 600 yd above the schoolhouse microscope (S 9170) the fragments tend to merge into the surrounding rock. The main mass of the section examined consists in part of a mosaic of quartz and felspar throughout which are scattered numerous small flakes of secondary biotite, minute greenish grains (? hornblende), and magnetite, and in part of quartz grains in a fine brownish matrix. Other portions, again, break up into a mosaic of micropoikilitic felspar, in which the secondary minerals are embedded. Sometimes there is a marked parallel arrangement, and sometimes an appearance of brecciation (S 9173). In the less altered specimens the andesitic portions retain their original texture (S 9172).

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Certain altered dykes cutting the calc-silicate-hornfels south of Glen Ure were regarded by Kynaston as belonging to the hornblende-schist suite referred to on p. 69. They may, however, be pre-Cruachan-" Granite " forerunners of the Etive Swarm.

Dykes of the Etive Swarm.—A porphyrite dyke veined by the Meall Odhar Granite, 930 yd south-east of the southern lochan on Beinn Ceitlein, shows characteristically clouded felspars. Moreover, its groundmass is suspiciously coarse (S 11496).

There are only a few slides of dykes showing contact-alteration undoubtedly due to the Starav Granite. Two come from Allt Dochard in Sheet 45, Geol. Their felspars are to some extent clouded, and characteristic aggregates of brown biotite and green hornblende have been developed along with a very perfect granulitic texture (S 14182-3). This stream section is very interesting, for, as has already been pointed out, there can be no doubt that its numerous dykes are earlier than the closely adjacent Starav Granite, since they are freely cut by aplite veins. A suite of slides was accordingly prepared, and the general failure to detect clear evidence of contact-alteration in them confirms the view that fresh igneous rocks are not readily susceptible to conspicuous contact-alteration. The two cited above had been sheared before or during the heating process.

A very beautiful example of contact-alteration is afforded in Sheet 53 by a dyke exposed near the Starav Granite in the bed of Allt Ceitlein, a quarter of a mile E.S.E. of Glenceitlein cottage (S 13762). There is a suggestion here of previous albitisation, with slight introduction of soda. Another good example comes from across Glen Etive, from Allt nan Gaoirean, nearly 600 yd above the schoolhouse

(S 14178). Other slides from Allt nan Gaoirean suggest contact-alteration in the coarseness of their ground, but the appearances are scarcely decisive (S 14175, 14177).

Apart from the cases quoted above, there are a few other hypabyssal rocks known in the district, showing definite contact-alteration, which cannot, however, be ascribed with certainty to any particular intrusive mass.

A porphyrite dyke (S 11502), cutting the Meall Odhar Granite in a burn, 1167 yd S.E. of the south lochan on Beinn Ceitlein, shows unmistakable contact-alteration in the condition of its felspar and ferromagnesian phenocrysts. The dyke has probably been altered by the Starav Granite, as it is within half a mile of the latter.

Another example in which contact-alteration is very strongly suggested is a thin microdiorite dyke (S 11506), cutting the Fault-Intrusion 667 yd N.E. of the 2897-ft Ordnance Station on Stob Dubh, and one and a half miles north of the Starav Granite.

Dykes of the Ben Nevis Swarm.—Many of the dykes cutting the Outer " Granite " of Ben Nevis have a suspicious appearance under the microscope, and in several slides contact-alteration is undeniable. It shows itself in much the same manner as in the lavas through the development of criss-cross brown biotite and pale-green hornblende, in place of original ferromagnesian constituents (S 8820, 14049), and of characteristic clouds of minute opaque inclusions in the felspars (S 14048a, 14425, 14427-8, 14440) ; two of the specimens showing altered felspars come from the Ben Nevis path within about a quarter of a mile of the margin of the Inner " Granite ". One or two specimens (S 14047) show a fairly perfect granulitic texture. This slice represents the chilled edge of a dyke cutting Outer " Granite ", while a slice from the centre of the same dyke (S 14048), cut across by Inner " Granite," is a microdiorite.

Early Fault-Intrusion, Glen Coe.—Some very good examples of contact-alteration are afforded by the Early Fault-Intrusion in its small outcrops in the tributary valley leading into Allt Coire Mhorair from the west. The hornblende phenocrysts are replaced by criss-cross brown biotite, while pale-green hornblende and biotite are abundantly developed in the groundmass (S 12359, 12360).

Main Fault-Intrusion.—The contact-alteration of the Main Fault-Intrusion of Glen Coe by the Cruachan " Granite " is quite clear in slides from the district south of Dalness (S 11503-5). Criss-cross brown biotite has been developed to a considerable extent in place of the original biotite phenocrysts, while pale-green hornblende is abundant in the groundmass ; the felspar phenocrysts in some cases show the tell-tale cloudiness (S 11505), and it is interesting to note that previous incipient albitisation, probably accompanied by introduction of soda, is evidenced by veins of more alkali felspar extending along what seems to have been a system of cracks ; this more alkali felspar is unclouded.

Moor of Rannoch " Granite ".—Only one of the slides which Grabham had cut of the Moor of Rannoch " Granite " at its junction with the Fault-Intrusion in the Coupall and Etive Rivers shows contact-alteration of the type discussed in the preceding paragraphs. In this slide (S 12751) an aplite vein runs between the Fault-Intrusion and the Rannoch " Granite," and the biotites of the latter seem to have been partially recrystallised as aggregates. Even here it is possible that the biotite clusters really belong to xenoliths digested by the Rannoch " Granite ".

Glen Ure Augite-Diorite.—The small boss of augite-diorite cut by the Cruachan " Granite " in Glen Ure affords a good example of contact-alteration. Most of what appear to have been originally large crystals of augite are now replaced by bladed aggregates of pale-green hornblende in (S 10125). In another slide (S 15877), cut across the actual contact, the nature of the alteration is less obvious. Here the big augite crystals are pseudomorphed by single hornblende crystals which retain small irregular relics of the originals.

Kentallenite at Kentallen.—In the 1916 edition of this memoir, Kynaston, as we have seen above, pointed out that a characteristic clouding of felspars (by dust or minute oriented needles) is a very common result of contact-alteration. The present writer further suggested that such clouding, though undoubtedly a contact-effect, had resulted during regeneration of felspar previously modified by weather or some other agent of change. Since then MacGregor has studied the phenomenon over a wide field and has come to the conclusion that previous alteration is not indicated (1931, pp. 526-7). It is probable that the truth lies somewhere between these two alternatives : perhaps in some cases preparatory alteration may have been required ; while in others it may not have been essential. An instance where it seems to have been important has already been discussed in relation to the type kentallenite at Kentallen, west of the Ballachulish Pluton (p. 212).

Effects Resembling Contact-Alteration

There are certain intrusions which show effects sufficiently like those produced by contact-metamorphism to be worthy of mention in this chapter. Some of the more or less horizontal lamprophyre sheets have a conspicuous development of green mica (S 11527, 12888-9), in part pseudomorphing hornblende. Tremolite has also been produced (S 12889). Similar changes are seen in various microdiorite and allied dykes (S 11475, 11550, 11581, 14410-1, 14416-7, 14419), the last five from the multiple dyke of Fig. 34. The biotite in these cases differs from that produced by contact-alteration in its greener colour and its tendency to occur with a chloritic habit in radiating growths or wavy bundles.

Similar hornblende and biotite aggregates have been described by Flett as characteristic of a group of lamprophyres in Perthshire (1905, pp. 125-130). More recently Flett (1910, p. 304) has shown that hornblende and green biotite figure among the decomposition products of the quartz-dolerites of Central Scotland, both in pseudomorphs after augite and in patches in the groundmass. In these quartz-dolerites contact-alteration by an independent intrusion is out of the question.

In the light of the available evidence it seems probable that this particular type of alteration is in many cases a juvenile decomposition. In other instances, however, it may well have had an external cause, for it is often strikingly developed in the Early Fault-Intrusion (S 12932, 13405, 14109) within the contact zone of the Fault-Intrusion proper, north of Glen Coe. E. B. B.

CHAPTER XIX

RUDHA NA H-EARBA OUTLIER OF SUPPOSED MIDDLE OLD RED SANDSTONE AGE

RUDHA NA H-EARBA is a promontory of the north-west coast of Loch Linnhe. It obviously lies between two branches of the Loch Linnhe or Great Glen Fault. The outlier consists of a considerable patch of breccia and red sandstone, discovered by Grant Wilson. The sediments rest unconformably on the schists and their felspathic veinings and have a gentle dip towards the S.W. The pebbles found in the breccias are composed of the local complex schistose rocks and pink felsite. "Though no fossil evidence to prove their age has been obtained, the rocks of this outlier greatly resemble those of the basement members of the Orcadian Old Red Sandstone of the Moray Firth Basin" (Sum. Prog. 1904, p. 69).

This comparison of the Rudha na h-Earba beds with the Middle or Orcadian Old Red Sandstone is due to Peach. It must be remembered that an elongated outlier of the formation was already well known along the course of the Great Glen at the head of Loch Lochy (Sheet 63, Geol.). Strips of similar material, greatly sheared, have since been found by G. S. Johnstone and J. E. Wright bordering the south-east shore of the loch to near its outlet (Sheet 62, Geol.; *see* Sum. Prog. 1953 b, p. 37). E. B. B.

CHAPTER XX

IGNEOUS ACTIVITY LATER THAN THE OLD RED SANDSTONE

INTRODUCTION

THE rocks considered in this chapter are a number of basic dykes, mostly in Ardgour but a few south-east of Loch Linnhe, and a volcanic neck in the valley of Allt Coire na Bà, a mile and a half north of Kinlochleven. At least one of the dykes as well as the neck may safely be classed as Permian. The majority of the dykes are probably Tertiary.

The main distinction between Permian and Tertiary igneous rocks in Scotland is provided by the former's typical alkalinity and the latter's typical calc-alkalinity. This criterion was first applied by Harker (1918, proc. p. lxxxvii) ; and it groups most of the post-Old Red Sandstone alkaline intrusions of the West Highlands along with the Permian lavas of Exeter and Ayrshire and the famous Oslo complex of Norway. Harker's view is now generally accepted (*cf.* Richey 1939, p. 416 ; MacGregor 1949, p. 137), having received support both from field evidence and from determinations of helium content (Urry and Holmes 1941).

It must, however, be admitted that there is in the West Highlands sufficient overlap of character between supposed Permian and undoubted Tertiary intrusions to render the alkalinity separation unreliable in a number of individual cases. This naturally led to doubts for many years as to whether all the West Highland alkaline intrusions might not really be Tertiary variants, a view long supported, more particularly, by Flett. One of the chief reasons for rejecting this alternative is that the alkaline rocks of the mainland, wherever seen in contact with calc-alkaline, are cut by the latter.

Four field characteristics help to distinguish the supposed Permian and Tertiary intrusions from one another.

(1) Most of the former are thoroughly basic or ultrabasic camptonites and monchiquites, and are very prone to develop pinkish felspathic spots, or ocelli, containing needles of hornblende or flakes of biotite. Such ocelli are almost unknown among the undoubted Tertiary intrusions of like basicity. Admittedly somewhat similar developments occur among Tertiary quartz-dolerites, but these latter are distinguishable on other grounds. The employment of ocelli as a diagnostic feature was among the lessons taught by Clough to his colleagues (*cf.* Bailey and others 1924, chap. xxxv).

(2) The supposed Permian dykes show a marked tendency to pustular or nodular weathering, much more so than do Tertiary associates.

(3) In many districts direction helps to separate the dykes of the two suites, but this criterion fails round about Mull (including Sheet 53), where both sets tend to run roughly west-north-west.

(4) To the north-west of Sheet 53, in the mining district of Strontian and in Ardnamurchan, Moidart and Arisaig, camptonitic dykes are often significantly associated with crushing and mineralisation. This feature was first recognised and carefully investigated by V. A. Eyles in 1921, in Ardnamurchan. It has since been found by the same worker and his colleagues to hold throughout the considerable area mentioned above (Sum. Prog. 1931, p. 64 ; 1932, p. 60 ; 1938, p. 72).

We have noted that the camptonite-monchiquite dykes are cut in many observed instances by Tertiary basalt dykes. On the other hand several camptonite dykes in the Ardnamurchan and Arisaig districts are known to cut small quartz-dolerite bosses assumed on other grounds to be of Permo-Carboniferous age (Sum. Prog. 1936, p. 80 ; MacGregor 1949, p. 140).

Although camptonite dykes are numerous in districts of the West Highlands which also retain extensive spreads of Trias, no contact of camptonite and Trias, either unconformable or intrusive, has rewarded careful search. In fact only one dyke that may be claimed as belonging to the Permian suite has been seen in this position, and it is there duly cut off by the Triassic unconformity. Richey has given the following account (1939, p. 418). " In one locality [of Morvern], a basic dyke was traced by Dr. J. B. Simpson up to the base of the Trias, and continued no farther. It was found clearly to be older than the basal bed of the Trias. This bed is a cornstone, and copious veins from it traverse both the underlying schists and the dyke. The latter resembles in rock-type the basalts that accompany the camptonites, but, it must be admitted, these basalts are themselves indistinguishable in composition from the undoubted Tertiary dykes of the neighbourhood ".

Accordingly we must accept as a surprising fact that scarcely any of the supposed Permian suite found in pre-Triassic rocks extend to the Trias unconformity. This presumably points to an original sharp upward termination of the dykes. A possible explanation is that magmatic pressure was relieved wherever a dyke attained local access to the surface, either for itself or its gases. E. B. B.

PERMIAN DYKES AND NECK

Dyke at Meeting of Three Waters, Glen Coe.—A group of west-north-west dykes has been followed from Sgòr nam Fiannaidh, along and across Glen Coe, and up and down the slopes of Buachaille Etive Beag. There is generally only one dyke, a few feet thick, in the group. Erosion of such a representative has been responsible for the straight gorge into which the River Coe turns at the Meeting of Three Waters (p. 139).

A specimen taken from this locality proves to be a somewhat decomposed rock of monchiquitic affinities (S 11913). The chief mineral is a pale purple augite. Strongly pleochroic biotite is abundant, as also is magnetite. Olivine is represented by pseudomorphs. Analcite occurs in big clear patches, allied to amygdales, as well as in the groundmass associated with chlorite and other decomposition products. There is more felspar present than in typical monchiquites, but scarcely enough to warrant placing the rock with the camptonites.

The Glen Coe monchiquite cuts the Old Red Sandstone lavas, the Fault-Intrusion and the north-east dykes of the Etive Swarm. There can be no hesitation in referring it to the same epoch as the north-west camptonite dykes which Kynaston found traversing the Starav Granite in Sheet 45 (Geol.). H. B. M.

Mineralised Dyke, Ardgour.—In Sheet 53 a north-westerly dyke is shown entering the western margin of the sheet near Sgùrr a' Bhuic, whence it passes through Garbh Bheinn and approaches Loch Linnhe at Inversanda Bay. It is quite probable that the same fissure has been used by both Permian and Tertiary intrusions. At any rate the mineralised portion described below is almost certainly Permian.

The locality is easy to fix on the one-inch map. The dyke, as a whole, is shown as cutting an east-north-east felsite 1200 yd S. of E. of the summit of Garbh Bheinn, and then, a little further east, as sending off a couple of branches. This occurs at the head of a gully, which may be taken as a landmark in the field. For the next 80 yd the dyke is mineralised.

Fifty yards along the gully K.C. Dunham, in 1946, measured the following section with an inclination of 75°-80° N.E. :

Gneiss of S.W. foot-wall
Dyke : 6 in.—6 ft
Breccia with fragments of dyke and gneiss in a chalcedonic and carbonate matrix : 3 ft
Barytes vein with a little galena : 1 ft
Gneiss, impersistent, giving place downwards to white trap : 1 ft 6 in.
Dyke, not in condition of white trap : 3 ft 6 in.
Gneiss : 2—3 ft
Dyke : 4 ft
Gneiss : 3 ft
Dyke : 4 ft
Gneiss of N.E. hanging wall

A dyke specimen (S 10938) proved to be a fine-grained olivine-basalt, much decomposed.

E. B. B.

Coire na Bà Neck.—A patch of red breccia is met with on the eastern slopes of the valley of Allt Coire na Bà. Its northern end is obscured by an extensive landslip, but the total length of the outcrop cannot much exceed a quarter of a mile, while the breadth is about 50 yd. The breccia contains rounded pebbles of quartzite as well as angular fragments of the same material. Small pieces of a peculiar fine-grained red sandstone have also been found, but no volcanic ejectamenta. The junction with the surrounding quartzite appears to be vertical and irregular, suggesting that the breccia occupies an explosion vent. In support of this view the breccia at one point has been invaded by a basic igneous rock now exposed in a small stream where it is full of xenoliths picked up from the breccia.

Even in the field the highly basic character of the intrusion is obvious, and small phenocrysts of olivine and augite can easily be recognised. Thin slices (S 12906-7, 14083-5, 14938) show that felspar is absent, except in the vicinity of quartzite xenoliths (S 12906). A pale purple augite, occurring partly in little zoned phenocrysts, but more especially in a multitude of minute prisms, is the dominant mineral. Olivine is well formed and abundant, and sometimes fresh (S 14085). Biotite is an accessory. By far the most interesting feature of the rock is abundance of fresh nepheline (S 14083), first recognised by Maufe. The nepheline occurs in relatively large crystals, enclosing the other constituents in poikilitic fashion. The Coire na Bà rock affords the finest example of a nepheline-basalt yet known in Britain. Unfortunately, in most of the specimens collected, the nepheline has decomposed, and the groundmass consists of chlorite and analcite.

W. B. W.

TERTIARY DYKES

Ardgour.—Dykes of basaltic or doleritic appearance in the field, and of a more or less west-north-westerly trend, are much more commonly met with on the north-west side of Loch Linnhe than on the south-east ; and they become quite abundant in the vicinity of Glen Tarbert and further south. They cut the " granitic " rocks of the district and also the felsite dykes. As explained above some of them are probably Permian and others Tertiary ; but separation of the two suites has as yet scarcely been attempted.

The majority of the dykes measure only a few feet across, but one important example, followed north-westwards past Garbh Bheinn, measures about 100 ft for a distance of a mile ; it here assumes, as might be expected, a thoroughly coarse doleritic texture. This broad dyke is probably Tertiary or Permo-Carboniferous, since the Permian dykes of the West Highlands are characteristically rather narrow. Further south-east the same fissure is occupied by the mineralised dyke described above under the Permian heading, so that it seems probable that it has been injected at two widely separate times. E. B. B.

South-East of Loch Linnhe.—A small group of basic west-north-west dykes has been traced intermittently across the " granites " of Ben Nevis, through Allt Coire Giubhsachan, and over the slopes of Binnein Beag. In the latter position there are five parallel dykes with an average thickness of 4 ft apiece. Specimens from Ben Nevis (S 14430) and Binnein Beag (S 12886-7) agree in character. The dykes are fine-grained ophitic olivine-dolerites, or tholeiites, with faintly purple augite and a little intersertal material. They certainly belong to the Tertiary suite.

Another parallel group of dykes has been traced south-eastwards along Gleann Fhaolain, where one of them follows the Glen Coe Fault and has been crushed by recurrence of movement along the old line of weakness. These dykes cut the north-east porphyrites. H. B. M.

A thin representative of the same group has been met with crossing the more easterly of the two streams that enter the River Etive half a mile east of Dalness. This thin dyke has been traced east-south-eastwards into a great slack that follows the same direction. A specimen (S 11482) proved on examination to be too decomposed for accurate determination. C. T. C.

CHAPTER XXI

FAULTS

Introduction.—Chapter xii has been devoted to the Boundary-Fault of the Glen Coe Cauldron-Subsidence and chapter xiv has dealt incidentally with the corresponding fault that encircles the lavas of Ben Nevis. In addition a subsection of chapter xiii has been given to the Allt Buidhe Fault connected with the " Granite " Complex of Etive. This fault enters Sheet 53 from the south, across a broad belt of calc-silicate-hornfels, and can be easily identified in Pl. IV, p. 63. Its northward continuation is responsible for much shattering of rocks in the bed of the River Creran above Barnamuc.

Such shattering has again and again guided subsequent erosion on a large or small scale, as set out in chapter i and in programmes for road excursions in Glen Coe, chapters vi and xi.

Many faults recorded on the Survey's six-inch field-maps are accompanied by very minor displacement of adjacent rocks. Most of these have been intentionally omitted from the published one-inch Sheet 53, or have been indicated there merely by the words SHATTER BELT. This policy has been adopted to avoid obscuring other data presented on the map. At the same time one must remember that a shatter-belt along a fault, even if accompanied by very small displacement, may well be of considerable economic as well as scenic importance. It may, for instance, render a particular site unsuitable for a reservoir dam or even a reservoir floor ; or it may let water into or out of a tunnel ; or it may add difficulty to the regular shaping of a tunnel ; or, worse still, it may lead to fatalities as a result of roof-falls. Accordingly in many cases advance location of shatter-belts is of high importance to engineering projects.

In what follows special attention will be paid to the Great Glen or Loch Linnhe Fault, which rivals in scientific interest the boundary-faults of Glen Coe and Ben Nevis. Then a few other individual faults will be selected as noteworthy for one reason or another. Finally a more minute account will be offered of faults met with in a sample area, the Alltchaorunn district, Glen Etive.

Great Glen Fault.—The Great Glen Fault runs north-east and south-west right across Scotland. It is accompanied by much shearing and shattering, which has guided the erosion of a continuous large-scale hollow. This is the Great Glen with its series of fresh-water lochs connected by the Caledonian Canal. At its two ends the hollow is filled by the sea to give the Moray Firth, on the east coast, and Loch Linnhe in Sheet 53, on the west.

In the Moray Firth the fault brings Jurassic rocks on the south-east into contact with schists and Middle Old Red Sandstone on the north-west. In Mull, beyond Loch Linnhe, its effect upon Jurassic rocks is much less obvious. The main movements along the fault are certainly pre-Mesozoic.

At the head of the Moray Firth, in the Inverness district, Middle Old Red Sandstone is exposed on both sides of the fault ; and at one point Horne has estimated that this great sandstone formation extends 6000 ft deeper on the south-east side than on the north-west (*in* Horne, Hinxman and others 1914, p. 68). This is a matter that particularly affects Sheet 53 since the conglomerate at Rudha na h-Earba (chap. xix) seems to be part of a series of strips of Middle Old Red Sandstone reaching south-west from Inverness along Loch Ness, Loch Oich and Loch Lochy. The local evidence will be considered presently.

In Sheet 53 as a whole the influence of the Great Glen Fault upon schist distribution is unusually striking. The schists that lie to the south-east of the fault are very much less highly metamorphosed than those of Ardgour to the north-west.

The effect of the Great Glen Fault upon the Jurassic of Moray Firth, the Middle Old Red Sandstone of Inverness and the Schists of Sheet 53 has been very generally ascribed to downthrow towards the south-east (including in this term

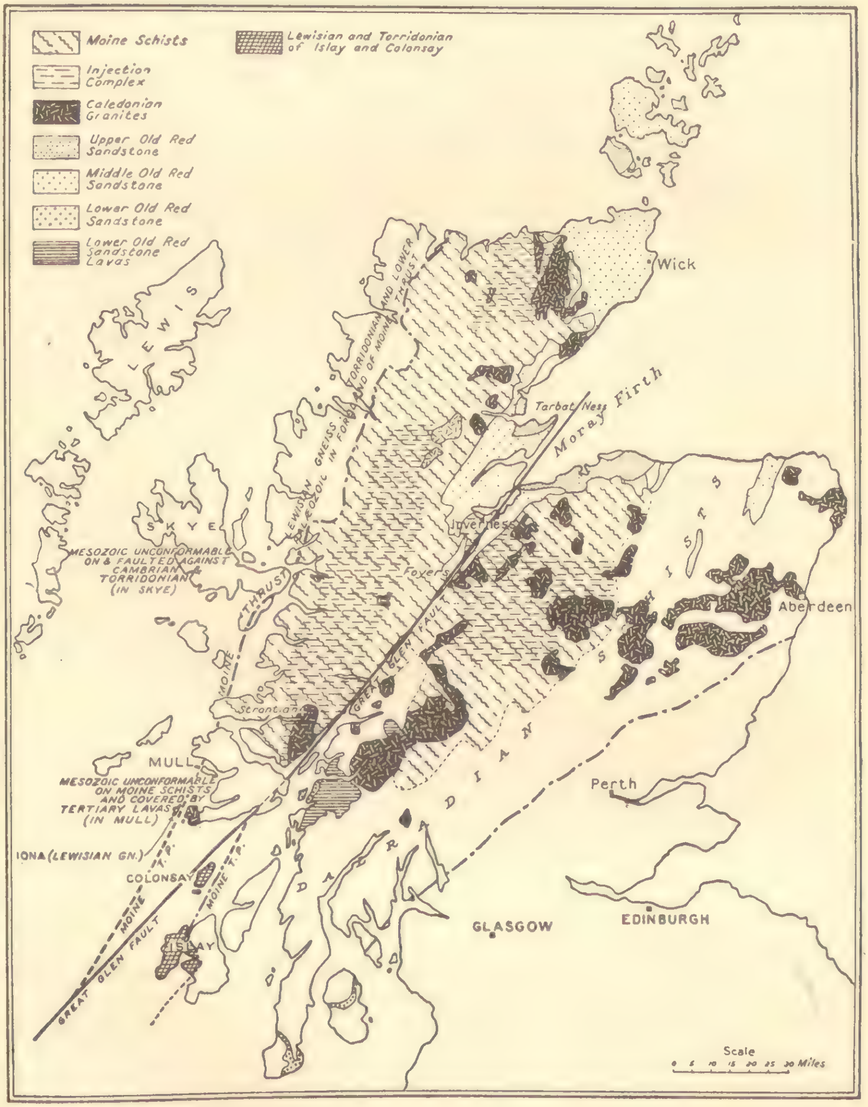


FIG. 40. Geological map of the Scottish Highlands to show the present position of the Moine injection complexes, the Strontian and Foyers granites, and the Moine Thrust-plane, after W. Q. Kennedy

(Reproduced, by permission, from *Quart. Journ. Geol. Soc.*, vol. cii, pt.i, 1946, fig. 2) steep over-thrusting from the north-west favoured by George Barrow). Apparently the only hint of an early appeal to wrench- or tear-faulting is found in a description of a fault at Allt Mòr in the Loch Ness area, a fault which Cunningham-Craig has claimed to belong to " the same system " as the neighbouring Great Glen Fault. " Horizontal slickensides," he goes on to say, " prove that lateral movement took place along this [Allt Mòr] line of disruption, as was the case with most, if not all, of the north-east and south-west fault lines " of the Highlands in general (*in* Horne, Hinxman and others 1914, p. 70). Later Kennedy, quite independently and much more emphatically, came to the same conclusion. He based on various lines of evidence, of which four are selected for discussion below (*in* Geikie, J., 1940, pp. 169-171 ; Kennedy 1946 ; 1948 ; 1949).

(1) The Great Glen Fault, as Cunningham-Craig first pointed out, seems to belong to a series of great wrench-faults, some of which have been interpreted as such since quite early in the present century. Kennedy lists the Strathconon, Strath Glass, Laggan, Ericht-Laidon, Tyndrum and Loch Tay Faults (1946, fig. 4, p. 56). He points out that all these faults are sinistral, that is, if one looks across their course one sees a relative displacement to the left. Also, this displacement is considerable—up to 4-5 miles in the case of the Ericht-Laidon Fault. The displacement Kennedy claims for the Great Glen Fault is also sinistral, and it amounts to 65 miles. It is the exceptional magnitude of this figure that impresses one with the need for caution.

(2) A great belt of regional injection affects the Moine Schists near Strontian and to the north-east (Fig. 40) ; and another extends east from Foyers. Kennedy correlates these two belts as really one and the same, displaced by the Great Glen Fault. Most people regard injection zones as fed from an underlying source. Accordingly, truncation of the Strontian injection zone by *subsidence* along the Great Glen Fault would imply subsidence to the *south-east* at the site now occupied by Loch Linnhe ; whereas truncation of the Foyers injection zone by *subsidence* along the Great Glen Fault would imply subsidence to the *north-west* in the present Foyers locality. Such a contrast of downthrow direction, where downthrow is on a large scale, is very difficult to accept. It appears more probable that the displacement indicated has been horizontal rather than vertical. The horizontal distance involved is about 65 miles and is sinistral.

(3) In Sheet 53 Kennedy considers that the difference of metamorphism on the two sides of the Great Glen Fault is too great to be reasonably explained by downthrow towards the south-east. Admittedly, the downthrow would have to be immense ; but marked differences of metamorphism are apparent on the two sides of the boundary-faults of the Glen Coe and Ben Nevis Cauldron-Subsidences, where only vertical movement can be invoked (pp. 71, 179).

(4) After realising the implications of the evidence considered under heading (2), Kennedy wondered if the Strontian " Granite," which he knew well, might not have been originally united with the comparatively unknown Foyers " Granite " (Fig. 40) to form a single complex. He therefore undertook a rapid examination of the Foyers " Granite," and found in it the same association of types as at Strontian with the same time-sequence and with a complementary arrangement of outcrops (1946, fig. 6, p. 62). He has summarised his comparison as follows : The Great Glen Fault " truncates the Strontian Granite, the southern portion of which, according to the detailed structural evidence, is missing. The missing portion, moreover, can be identified in the Foyers mass which outcrops on the other side of the fault-line some 65 miles to the north-east and is similarly truncated by the fault. These two major Caledonian intrusions consist of identical rock types and are structurally homologous". It will be noted that the Strontian—Foyers " granite " evidence is exactly similar to the injection-zone evidence, only more appealing. Even if we are sufficiently cautious to refuse to accept as proved the correlation of the two " granite " complexes we still must admit that the evidence which they afford against a *subsidence* explanation is extremely strong. Truncation of the Strontian " Granite " by subsidence would almost certainly entail subsidence to the *south-east*, whereas truncation of the Foyers " Granite " would equally strongly imply subsidence to the *north-west*. In all the circumstances Kennedy's interpretation seems probable ; and we may note that it has been somewhat strengthened through detailed investigation of the Foyers outcrop undertaken by Mould (1946). Her map differs in some important respects from that quickly drawn by Kennedy, but it is the same in essence. " The present detailed study of the Foyers complex has," she says, " shown its likeness to the Strontian mass in many particulars, but has also revealed some differences " (1946, p. 264). When she enumerates these differences one finds them surprisingly slight.

Kennedy's suggested Strontian—Foyers displacement may perhaps be parallelled by a possible Colonsay—Ballachulish displacement of like apparent direction and magnitude. In Colonsay, named on Fig. 40, a typical kentallenite, appinite, augite-diorite association matches exactly in lithology, though not in country-rock, the Ballachulish concentration illustrated in Fig. 18. It is tempting to attribute the present separation to movement along the Great Glen Fault ; if so, the fault must run south-east of Colonsay, not north-west as shown by Kennedy in Fig. 40. There is independent evidence that such is its true position.

Let us now return to Sheet 53 and consider the outlier of supposed Middle Old Red Sandstone conglomerate at Rudha na h-Earba. It rests unconformably on felspathised, highly metamorphosed Moine Schists with granite veins. Accordingly it lies on the north-west side of the main branch of the Great Glen Fault, for this runs along Loch Linnhe to introduce the slightly metamorphosed schists of Rudha Mòr, Shuna Island and the Appin mainland. Thus it is practically certain that the main branch of the Great Glen Fault has not moved with important downthrow to the south-east since the deposition of the Rudha na h-Earba conglomerate. If it had, one would expect to have found an extensive south-eastern outcrop of the Rudha na h-Earba formation. This argument does not, of course, preclude important south-east downthrow prior to Rudha na h-Earba conglomerate times ; and so it must not be taken as a demonstration of the emplacement of the conglomerate by wrench-faulting. A possible alternative is that the rocks forming the Rudha na h-Earba peninsula occupy a narrow trough-fault, or graben, developed after the main faulting episode. Such a strip would give no clue as to the nature of previous movements, vertical or horizontal. In Mull, further south-west, a narrower strip includes Kimmeridgian which appears to have escaped pre-Cenomanian erosion through subsidence into a graben following the course of the Great Glen Fault (Bailey *in* Lee and Bailey 1925, p. 114 ; Manson *in* Sum. Prog. 1934, pp. 83-4).

The Rudha na h-Earba conglomerate has been correlated with strips of Middle Old Red Sandstone seen intermittently at Loch Lochy, Loch Oich and Loch Ness further north-east along the Great Glen, and there is no doubt at all that the Middle Old Red Sandstone has suffered intense movement along the Great Glen Fault. Kennedy has proposed that the initiation of the faulting dated from Carboniferous times. The writer, however, thinks that the fault was already active in Lower Old Sandstone times. This is suggested in Sheet 53 by the manner in which a zone of granite-veins and elongated granite-bosses flanks Loch Linnhe as far south-west as Inversanda Bay (p. 189). It looks as though ascending magma, presumably of Lower Old Red Sandstone age, was guided by the Great Glen Fault. In Druim na Maodalaich this same alinement appears in an offshoot of the Strontian " Granite " Complex. Accordingly it is probable that the Great Glen Fault has to some extent functioned as a guide to Strontian magma, even though later it may have cut the resultant Strontian-Foyers Pluton into two.

When Kennedy wrote of Foyers he thought that the strip of Middle Old Red Sandstone, which is shown in Fig. 40, was essentially dipping unconformably off the Foyers " Granite ". Mould has since shown that the relationship is considerably more complex. The Foyers " Granite " is often separated at outcrop from the Middle Old Red Sandstone by schists. These are partly Moines, corresponding with the normal country-rock of the " granite " ; but for two miles they consist of a narrow strip of problematical " Gleann Liath Series ". The latter consists of " coarse gneisses, with associated limestones, intruded by basic hornblende-diorite and veins of pegmatite and granite "—a description that suggests comparison with the Glen Scaddle rocks of Sheet 53. The Gleann Liath Series is faulted against the country-rock Moines on the south-east, and is covered by north-west-dipping unconformable Middle Old Red Sandstone on the north-west. As Mould has traced the unconformity from Moines to Gleann Liath Series (1946, p. 263) it seems clear that some of the important faulting of the district is earlier than the local Middle Old Red Sandstone. Mould herself clearly expresses this opinion when she says : " The Foyers 'Granite' is traversed by many crush zones and movement lines related to the Great Glen Fault. The movements have evidently spread over a long period of time ; some appear to be earlier than the Middle Old Red Sandstone " (1946, p. 256).

It is now time to warn readers that Kennedy's views have been strongly contested by Shand (1951). The latter found that at one point in the glen the width of concealed rock, due to surface deposit (presumably covering fault-shattered material) measures only a third of a mile. He concluded therefore that available exposures along the glen are close enough to give the essential features of the shatter-belt between. In these exposures he failed to find horizontal slickensides—this in spite of his visiting Cunningham-Craig's record at Allt Mòr, which he describes as unsatisfactory owing to rock weathering and cover by brush wood.

He also failed to find mylonite ; but he explains that by mylonite he means flinty crush-rock, or pseudo-tachylite, with which he was very familiar in the Parys Mountain of South Africa. As the development of flinty crush-rock presumably depends rather upon *rapidity* than upon *integrated extent* of movement, this is not necessarily significant. In regard to one or two specimens, collected by Eyles as showing minute veins of flinty crush-rock, he remarks that " they can hardly be considered to throw any light on the problem of the Great Glen ". Taken by themselves they certainly do not.

Shand's statements regarding dearth of horizontal slickensiding along the Great Glen do constitute an obvious difficulty for Kennedy's interpretation ; and it is to be hoped that they will lead to further intensive study.

On the other hand his disrespectful treatment of the crush phenomena along the glen and his insistence upon flinty crush-rock as a necessary accompaniment of extensive wrench-faulting came as a surprise to many Scottish geologists. A carefully documented reply was soon furnished by Eyles and MacGregor (1952).

In so far as Sheet 53 is concerned considerable shatter phenomena are a general feature of the north-west shore of Loch Linnhe and also of the south-east shore in the narrow section between Fort William and Rudha Cuilcheanna ; and at one place, but only one, a sample is exposed of the altogether exceptional shearing that is thought by most geologists to be truly characteristic of the fault zone. The locality is the foreshore for about a mile south-west of Fort William *as exposed at low tide*. The following account was published long before Kennedy had thought of a wrench interpretation of the Great Glen Fault (Bailey 1934a, p. 471).

Here we see " a pale grey set of schists with what appear at first sight to be beds and lenticles of rusty-weathering sedimentary calcareous schist, the whole affected by terrific breaking and mylonization hading steeply, as a rule, towards the north-west. Careful search and comparison show that these grey schists have been derived for the most part from bedded semi-siliceous rock of more or less Eilde Flag type, and that the associated calcareous bands and lenticles are foliated calcitized (or dolomitized) lamprophyres of Devonian age ; there are also a few porphyrites. In places, the mashed mylonized assemblage develops into a foliated crush-breccia that might even be mistaken for boulder bed " with porphyrite pebbles.

Great Glen Subsidiaries.—Let us now turn to what may be termed subsidiary branches of the Great Glen Fault. To the north-west of the Corran Narrows of Loch Linnhe one such subsidiary is indicated on Sheet 53 as reaching north-east past Rudha Dearg. In the other direction it very likely connects with the branch that passes north-west of the Rudha na h-Earba peninsula between Inversanda Bay and Camas Chil Mhalieu.

Across, that is south-east of, Corran Narrows another subsidiary is mapped behind Druim na Birlinn. It has caused notable displacement of schist outcrops, and also has guided the erosion of considerable hollows. Hidden under raised beach (and therefore not coloured on the map) it is responsible for a north-south low-level pass, followed for half a mile by the main road west of Onich. North of this it has located the excavation of a stream gorge draining past Inchree.

Fault crossing Glen Nevis.—As shown on Sheet 53 by the words SHATTER BELT (see also Fig. 16) a fault crosses Glen Nevis a little above the mouth of the tributary Allt Coire na Gabhalach. It has determined the course of the River Nevis for three-quarters of a mile, and is known to continue both to north-east and south-west.

Loch Leven—Loch-Eilde Mòr Fault.—An east-north-east shatter-belt has guided the erosion of Loch Leven and Loch-Eilde Mòr. It is often connected with a right-angle bend of the strike of the schists ; and it is argued on p. 95 that it may have been located by this bend. Broken rock along its course is especially well seen in streams at the head of Loch Leven, where SHATTER BELT is printed on the map ; and what is probably a continuation of the same smash is exposed in the bluff west of St. John's Church, Ballachulish. Displacement along this fault is unrecognisably small.

Glen Etive—Lairig Gartain Fault.—A great shatter-belt, parallel with Loch Linnhe, has been traced from the lower reaches of Glen Etive through Lairig Gartain and across the Blackwater Reservoir a little above the dam. It is shown on Sheet 53 by a dark brown line. Broken rock is visible at many places along its course. It is not possible, however, to determine precisely any displacement which it may have produced in the schists, lavas and " granites " that it traverses, for it has given rise to a broad hollow wherein exposures are poor and discontinuous. It is clear, however, that such displacements as occur must be comparatively trifling.

Faults West of Glenceitlein, Glen Etive.—A SHATTER-BELT is marked on Sheet 53 leading east from the head of Allt Bealach na h-Innsig. It affects both Leven Schists and Cruachan " Granite ".

Another crush-zone runs along the lowest reaches of Allt nan Gaoirean where the map shows Cruachan and Starav " Granites " in contact. E. B. B.

Faults of Alltchaorunn District, Glen Etive.—All the faults considered below are later than the north-east porphyrite dykes of the Etive Swarm. They mostly follow the direction of these dykes, or else run at right angles to the same. The north-easterly set of faults may be the earlier ; and the north-westerly may perhaps be of Tertiary—or Permian—age. Suggestive evidence is afforded in a burn about a mile west-south-west of Alltchaorunn House. Here a crush-band with calcite strings strikes north-north-east within a porphyrite dyke, and is cut by a somewhat similar crush-band striking north-west, or west-north-west, nearly parallel to a dyke of supposed Tertiary age. The latter can be easily identified on Sheet 53.

Let us now turn to the middle course of Allt a' Chaoruinn, where SHATTER BELT is printed on Sheet 53. The long reaches of the stream which run north-east or north-north-east mostly follow crush-planes ; and these, like the dykes of the neighbourhood, incline steeply south-east. The crushes are accompanied by many strings of calcite and some of quartz ; while the adjacent rocks have developed close parallel joints. In one example, a mile slightly west of south of Alltchaorunn House, a quartz vein attains a breadth of four feet.

Some north-north-east shatter-belts, crossing the two tributaries that enter this part of Allt a' Chaoruinn from the west, seem to be nearly vertical ; while an east-north-east fault that traverses the south end of Beinn Ceitlein inclines south. In places this last has effected considerable crushing ; but it has produced only very slight displacement of porphyrite dykes.

The most prominent of the north-westerly crushes of the district crosses Glen Etive half a mile west of Alltchaorunn House, and for five miles is marked by a dark brown line on Sheet 53. Just south of the glen its position is indicated by a deep erosion cleft on the hillside. Crushed rock is seen at one place in the bottom of this cleft, and porphyrite dykes have suffered a dextral displacement of 9 ft. Similar dextral displacement of 9 ft affects a quartz-porphyry dyke (the one that terminates further south a little before reaching the Meall Odhar Granite, p. 173). On the other hand, south-south-east of Alltchaorunn House, what appears to be the same crush-plane is accompanied by minor sinistral displacement of porphyrite dykes. This disagreement is not surprising as the shifts involved are in all three cases very small. The fault at the locality just cited is vertical, but more often it inclines to the south-west.

About a mile east of the quartzite summit of Stob Dubh a north-west crush, not indicated on Sheet 53, crosses the quartz-porphyry dyke mentioned above. Again there is dextral displacement, here measuring 9 ft.

A burn running slightly west of north joins the Etive about a quarter of a mile below Dalness. Various crush-bands and calcite veins keep nearly along its course. They do not displace dykes to any appreciable extent. C. T. C.

CHAPTER XXII

PLEISTOCENE AND RECENT

INTRODUCTION

THE present chapter deals with post-Tertiary happenings, and is virtually a reprint of what appeared on the subject in the 1916 edition of this memoir. For further information the reader may consult two important publications that have appeared in the interval. The first is the Geological Survey memoir by Hinxman and others (1923) on Corrour and the Moor of Rannoch in Sheet 54 immediately to the east. The second is a comprehensive synthesis by Charlesworth (1956) of glacial retreat phenomena considered consecutively throughout the Highlands as a whole. So far as Sheet 53 is concerned Charlesworth's subject is Late Glacial retreat during what he calls the Moraine or M Stage dating from the maximum of the Loch Lomond readvance. By this time most of the Islands, East Highlands, Midland Valley and Southern Uplands of Scotland had been denuded of glacial cover, the Moor of Rannoch had become a receiver instead of a distributor of western ice and much at any rate of the deposition of the Hundred-Foot Beach had been completed. Charlesworth's local findings in our district are given in his 1956 paper on pp. 826-830 with figs. 6a, 9 on pp. 811, 821 ; while his general conclusions are set out on pp. 769-781, 891-924 with figs. 21-23 and pl. i on pp. 898, 900, 923, 928.

ICE-SHEET AND VALLEY GLACIERS

Striae of the Maximum Stage.—All the great valleys of the district afford striated surfaces indicating a down-stream flow of ice. But as one ascends higher and higher, on to cols and ridges, one meets striæ with a direction more and more independent of the local inequalities of the topography. It is impossible to disentangle satisfactorily the striæ formed at different stages of the glaciation ; but in the following paragraphs an attempt is made to indicate the direction of ice-flow during the maximum development of the ice-sheet (Fig. 41).

There is good reason to believe that the hollow of Loch Linnhe, even at the maximum of glaciation, controlled a mighty stream of ice flowing south-west, and fed by converging currents from either side.

High-level striæ north-west of Loch Linnhe suggest that the ice-sheet reached its greatest elevation along a slightly sinuous north to south line of flow, which enters the map near Meall nan Damh, and extends southwards through Stob Mhic Bheathain, Beinn na h-Uamha, Sgòr Mhic Eacharna, Garbh Bheinn, Meall a' Choirein Luachraich, and Maol Odhar. East of this line of flow the ice-stream was definitely convergent upon the hollow of Loch Linnhe. West of it, it found an escape across the low-lying portions of Sheet 52 (Geol.), invading the hollows now occupied by Loch Shiel and Loch Sunart. This interpretation, and most of the records of striæ upon which it is based, are due to Grant Wilson. Where another observer is responsible his name is inserted in brackets in the enumeration given below.

Attention may be drawn more especially to striæ on Sgùrr Ghiubhsachain and south-east of Meall an Doire Shleaghaich on the ridge north of Cona Glen ; to the fine set between Meall Mòr and Druim Leathad nan Fias on the ridge between Cona Glen and Glen Scaddle ; to those on Sgùrr Dhomhnuill, Sgùrr a' Chaoruinn, Sgùrr na Làire (Peach), Meall nan Ruadhlag, Beinn na h-Uamha and A Bheinn Bhan on the ridge between Glen Scaddle and Glen Gour ; to those upon and west of Garbh Bheinn (Bailey) and on Sgòr Mhic Eacharna between Glen Gour and Glen Tarbert ; and finally to those west of Maol Odhar (Bailey) and east of the same (Maufe), and to those between Meall a' Choirein Luachraich and Meall a' Bhraghaid on the ridge south of Glen Tarbert. E. B. B.

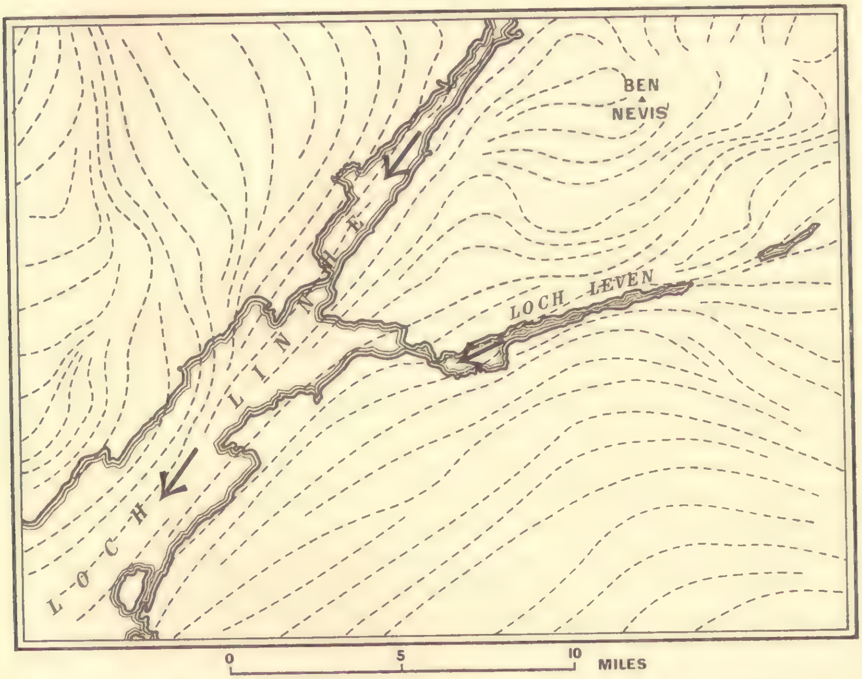


FIG. 41. Map of glacial flow-lines during the maximum stage of glaciation

South-east of Loch Linnhe the dominant feature of the ice-flow during the maximum of glaciation was the great Loch Leven current. Numberless striæ indicate a convergence of flow-lines upon Kinlochleven. From this point the ice crept south-westwards to unite eventually with the Loch Linnhe stream.

W. B. W., E. B. B.

Some of the other features of the diagram (Fig. 41) are more open to question. It is doubtful, for instance, whether the Ben Nevis range marked the position of an ice-shed at the maximum stage of glaciation, as suggested in Fig. 41, or whether it was completely overridden from the north-east. The former view has a certain amount of evidence to support it, for whereas striæ directed to the S.S.W. have been observed at 3600 and 2500 ft on the summit ridge of Aonach Beag, others running slightly east of north are met with on the col at the head of Allt Coire Rath at 2600 ft (Sheet 54, Geol.) ; these latter, however, may merely indicate the direction of ice-flow during a somewhat late stage of the period of recession, and one would not be surprised some day to find evidence of an earlier southward carry across this col, and across the range as a whole.

The curving flow-lines drawn farther east in Fig. 41, south-eastwards from Stob Coire Easain across Meall a' Bhùirich, and then south-westwards more or less along Glen Nevis, introduce another doubtful point. An east-south-easterly flow of ice from the Stob Coire Easain range is very well attested by striæ on the summit of Meall a' Bhùirich, but it is quite possible that at the maximum stage this current may have been stemmed and indeed reversed. E. B. B.

The glaciation of the eastern part of Mamore Forest south of Glen Nevis was affected by a general ice-flow from a centre or centres of accumulation to the east, a little beyond the limits of Sheet 53, modified, either throughout, or only in the later stages of the ice-age, by a local dispersal from the mountains around Binnein Mòr. If the ice ever actually swept from east to west across these mountains we have now no record left of its passage. The conclusion to be drawn from the striæ is that the easterly ice divided on the flanks of the Binnein Range, sending one branch down Glen Nevis and another along the valley of Loch Eilde into the head of Loch Leven. The Loch Eilde ice-stream, reinforced by contributions from Binnein Mòr, joined hands with that coming due west along the Leven valley. There was thus a marked concentration of ice on the head of Loch Leven which, as already stated, must have contained an extremely powerful current.

The convergence of the ice west of Binnein Mòr upon the Loch Leven stream is very clearly indicated by S.S.W. striæ, running uphill out of the valley of Allt Coiré na Gabhalach, a little below the col leading across to Allt Coire na Bà.

W. B. W.

A less southerly trend is shown by high-level striæ on Am Bodach, a couple of miles west of the col just mentioned.

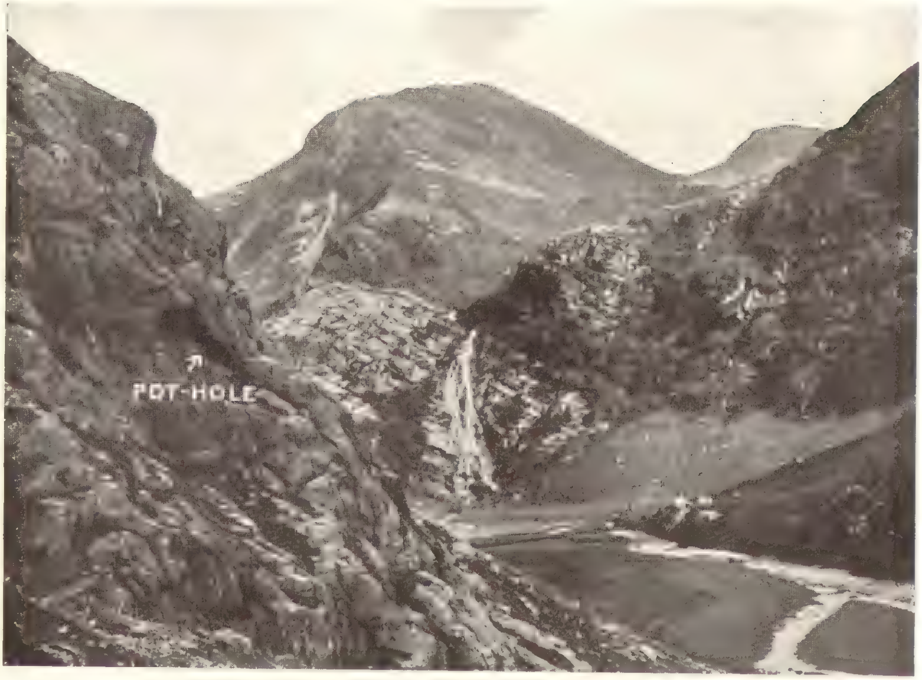
Three miles further north-west on Sgòr Chalum, which rises above the great bend of Glen Nevis, Grant Wilson found striæ indicating an escape of ice out of this glen travelling slightly north of west.

Farther south again Grant Wilson observed striæ running N.N.W. on Meall a' Chaoruinn, not much below the 3000-ft level. It would seem then that the Lairigmòr valley exercised a powerful influence upon the direction of ice-flow. But since it is extremely improbable that the ice at the head of Loch Linnhe ever escaped in any but a south-westerly direction, the flow-lines deduced from these high-level striæ on Meall a' Chaoruinn are shown in Fig. 41 as crossing the Lairigmòr valley farther on and bending round towards the south-west. That the flow of the ice did carry westwards out of this valley, just as it did in the case of Glen Nevis, is indicated quite definitely by striæ directed towards the west on Doire Bàn at 1500 ft, and west-south-west on the ridge east of Allt Meurach at 1300 ft above sea-level.

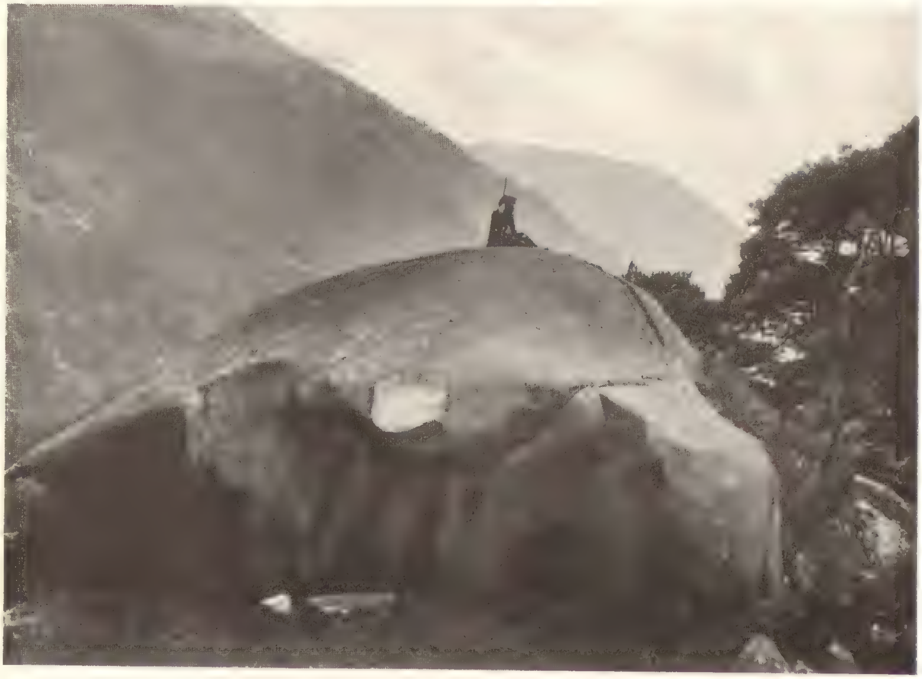
We may now turn to the district south of the Leven valley. The convergence of the ice upon Kinlochleven, and the subsequent swinging of the current into parallelism with the loch, are indicated by a profusion of ice-moulded and striated surfaces. Even on the top of the Pap of Glen Coe striæ have been preserved.

The onward march of the Loch Leven ice over the obstacle of Beinn a' Bheithir is particularly well shown by west-south-west striæ found by Grant Wilson on the north spur of Sgòrr Dhearg at an elevation of 3000 ft. Across the col at the head of Glen Duror the ice-current passed a little south of west.

In Glen Creran, Grant Wilson and Kynaston have found many striæ directed along the course of the glen. It is probable that even at the maximum stage of glaciation the ice more or less followed this great hollow though still tending to some extent to converge upon Loch Linnhe. In the valley of Allt na Muidhe,



AN STEALL, THE WATERFALL OF A VALLEY HANGING TO GLEN NEVIS
Water-worn crags on left due to stream cascading down marginal crevasse



ROCHE MOUTONNÉE, GLEN NEVIS, BY ROADSIDE ABOVE POLLDUBH
Note gap on " Stoss " side due to plucking

Grant Wilson has recorded south-west striæ marking the passage of Glen Coe ice across into Glen Creran.

High-level striæ have been scantily preserved on the volcanic rocks and " granites " south of Glen Coe. Still Maufe has obtained striæ directed west by south at the 2500-ft level on the south slopes of Bidean nam Bian ; while on the quartzite of Beinn Ceitlein and Stob Dubh, which lie within the " granitic " area, Clough and Maufe have found striæ varying between west-south-west and west at elevations of 2500 and 2800 ft. Probably Glen Etive, even in its lower reaches, was crossed, though obliquely, by the main ice-current.

Strong support for this view is afforded by Kynaston's observations in Sheet 45 (Geol.) which show that ice passed over the low plateau of Lorne, at the foot of the great granite mountains of Etive, in a direction slightly north of west. The reader may be referred to fig. 16 of the Geological Survey Memoir on Colonsay for a sketch map, compiled by Wright and Bailey, to illustrate the glaciation of the West Highlands south of Sheet 53. E. B. B.

Glacial Erosion.—The question of glacial erosion has been discussed already in chapter i. Reference will there be found : to the complex development of hanging valleys, including that of An Steall of Pl. XIII, 1 ; to the example of grinding and plucking illustrated from further down Glen Nevis in Pl. XIII, 2 ; and to the *moutonné* surfaces of the valleys of Allt Coire an Eòin, flowing north-east from Aonach Beag of the Ben Nevis Group, and of Amhainn Coir' an Iubhair, entering Glen Tarbert near Loch Linnhe. Instances of *moutonné* surfaces are numerous throughout the district, and a few may be mentioned from more accessible localities. The contact-altered Leven Schists, crossed by the upper path at Glen Nevis gorge, a couple of miles above Polldubh, are strikingly ice-worn. So, too, are unbaked rocks of the same formation by the roadside and along the shore east of North Ballachulish ; while further east glacial striping of the slopes, overlooking Loch Leven from the north, is often remarkable, with long gentle ridges and furrows descending at a low angle towards the west-south-west. Ice moulding of Leven Schists by the roadside in Glen Creran, near the southern limit of the map, and of Eilde Flags along General Wade's Military Road, east of Allt Coire Mhorair, is also particularly impressive. E. B. B.

The *massif* of Binnein Mòr presents a remarkable topographical peculiarity which probably finds its explanation in the glaciation of the district. The northern and eastern spurs of the mountain, which culminate in the summits of Binnein Beag and Sgùrr Eilde Mòr, are both trenched by passes with flat bottoms occupied by lakes. The huge valley, Coire Binnein, that lies between these spurs, was a distributing reservoir for ice during the later stages of glaciation, pouring it out across the passes. The ice-tongue which had its outlet between Binnein Beag and Binnein Mòr was tributary to the Glen Nevis ice, while that which escaped over the Sgùrr Eilde Mòr pass can be proved by its striæ to have swept round and become confluent with the Loch Eilde glacier. To the excavating power of these two glaciers and to their moraine accumulations must be ascribed the flat-bottomed passes and the lakes which occur on them. On the dark mica-schist slopes of Allt Coire na Gabhalach, below the Binnein Beag pass, there is an enormous accumulation of white quartzite debris, distributed by torrents which issued at several points from the front of the northern tongue of ice. W. B. W.

Boulder-Clay, Moraines and Erratics.—A small proportion of the glacial drift of the district has been mapped by Grant Wilson as boulder-clay, especially near the southern border of the map, west of Glen Creran. But elsewhere the dominant type is a loose, uncompacted, often more or less gravelly deposit with a hummocky topography, which corresponds with what is commonly designated moraine by Scottish geologists. True glacial gravels also occur, but these will be discussed later.

It must not be supposed that the morainic drift was wholly derived from rock surfaces exposed above the level of the ice. This is most certainly not the case. For instance, the Strontian " Granite " north of Glen Tarbert builds a high plateau, across which the shallow Gleann Féith 'n Amean drains, and yet, though the " granite " nowhere rises into a ridge overlooking the plateau, it has furnished the great majority of the boulders occurring in the morainic mounds upon its surface. It is clear, in fact, that the boulders have been derived by plucking, of the type discussed in chapter i (Plate XIII, 2). Similarly one can scarcely doubt that the " granite " boulders occurring in the myriad mounds upon the Moor of Rannoch have been derived from below, and not from the insignificant ridge which crosses the moor eastwards from Beinn a' Chrùlaiste. E. B. B.

The distribution of boulders of the Moor of Rannoch " Granite," west of the moor, shows the wonderful lifting power of the ice-sheet. Boulders of this rock have been observed on the face of Buachaille Etive Mòr at a height of over 2000 ft—one of them, on the col south-west of Stob Dearg, at about 3000 ft. It may be regarded as fairly certain that these boulders were picked up from the moor at approximately the 1000-ft level. G. W. G.

High-lying boulders of Moor of Rannoch " Granite " have also been met with on Aonach Eagach, north of Glen Coe, not much below 3000 ft. H. B. M.

It is not only the elevation to which the Moor of Rannoch boulders have sometimes been raised, but also their wide dispersal that entitles them to interest. The northern limit of their distribution has been traced from beyond the eastern limit of the map to near Kinlochleven. It runs approximately east and west, and lies less than a mile north of the river Leven. Its course, shown on Sheet 53, corroborates the evidence afforded by the striæ in regard to the westward flow of the ice in this part of the district during the maximum of glaciation. W. B. W.

There remains much useful work to be done in tracing the limits of boulder trails within Sheet 53. Grant Wilson followed kentallenite and augite-diorite boulders south-west along the course of Loch Linnhe from Kentallen and Ardsheal, and others coming down Glen Creran from Barnamuc, etc. ; but his data have not been preserved. Maufe and Grant Wilson have also drawn attention to the wonderful profusion of boulders of volcanic rocks from Glen Coe, exhibited in the River Laroch above Ballachulish Bridge. Again, the passage of ice across Glen Nevis during the maximum glaciation is clearly evidenced by numerous boulders of Ben Nevis " Granite " stranded on the north-east face of Bidein Bad na h-Iolaire. E. B. B.

As may be imagined, the distribution of boulders is an intensely complicated matter. Whereas the Moor of Rannoch figured, during the height of glaciation, as a centre of dispersal, later it became an area of accumulation. Glaciers from Càm Ghleann and the great valley of the River Bà (Sheet 54, Geol.) spread out over the moor in a general easterly direction ; and among the erratics thus distributed we may recognise volcanic rocks from the Sròn na Crèise and Meall a' Bhùiridh (Sheet 54) group of mountains (*cf.* Hinxman and others 1923, p. 84). H. K.

In keeping with this evidence a succession of particularly clear morainic ridges also occurs on the high ground east of Càm Ghleann. They cross a shallow hollow south of Creag Dhubh (Sheet 54), and point to an eastward overflow of ice from Càm Ghleann at the time of their formation. G. W. G.

Further north, striking termino-lateral moraines bulge westwards from the valley of Allt an Eoin Bhinn into a col between Beinn Bheag and Meall Bad a' Bheithe ; and others, more strictly lateral and less well-defined, line the eastern slopes of Beinn Bheag and the western slopes of Beinn a' Chrùlaiste opposite. All these morainic terraces slope gently to the north-east. By the time they formed it is quite possible that the hollow now occupied by the Blackwater Reservoir had become a receiver of western ice (*cf.* E. M. Anderson *in* Hinxman and others 1923, p. 85). Very clearly marked crescentic moraines at the west foot of Stob Beinn a' Chrùlaiste probably indicate a halt at a later stage when the ice-stream had dwindled back to Altnafeadh.

The crossing of boulder trails mentioned above is repeated again and again. It is well illustrated in Gleann a' Chaolais draining into Loch Leven. This glen, even at its head, retains much of the material brought by the main westward ice-flow, including great numbers of boulders of Moor of Rannoch " Granite " ; and yet right down to its mouth at Caolasnacon it is strewn with blocks of andesite carried down-valley from the crags of Aonach Eagach during the later stages of glaciation. E. B. B.

Since the morainic drift usually presents a hummocky unordered topography, the well defined terminal or lateral ridges mentioned above are exceptional. Additional terminal examples may, however, be cited from the north-east end of Lairig Gartain, Glen Coe, and from the stretch of Glen Etive between Alltchaorunn and Dalness. Two more will be mentioned in the next section.

G. W. G.

Glacial Drainage Erosion.—Two fine crescentic moraines occur at the lip of the hanging valley of Allt Coire Giubhsachan, south-east of Ben Nevis. One of them reaches the col that separates Meall Cumhann from Ben Nevis. Across this col there is a typical stream-channel, now dry and deserted. It was cut by waters issuing from a lakelet sustained at this level by the Allt Coire Giubhsachan glacier.

The channel just mentioned is one of the few in the district that can be referred to glacially diverted waters. In this respect there is a marked contrast between the West Highlands and the East. The West, owing to its greater snowfall, has suffered more from direct glacial erosion than the East ; its rocks are fresh and hard right up to the surface, and do not readily yield to water erosion.

In addition, the West was the true home of glacial conditions during the valley-glacier stage. The main glaciers were constantly joined on either side by tributary glaciers and by slopes of *névé*, and so did not afford an opportunity for marginal drainage. In the East the main glaciers invaded a district where local conditions of climate were not, strictly speaking, glacial at all, and there it is that marginal drainage phenomena have been developed in perfection.

While dealing with the subject of glacially directed water-erosion we may note another example furnished by Meall Cumhann, though of a different category from the last. The cliff face of Meall Cumhann, a little beyond the upper end of the Glen Nevis gorge, is beautifully water-worn, with hollow surfaces, and even gigantic semi-pot-holes, into which sheep have been known to scramble (Plate XIII, 1). The water-worn face is perhaps 200 or 300 ft high, and clearly marks the position of a marginal crevasse down which a torrent was wont to plunge, drilling great pot-holes, half in rock, half in the ice. Now, of course, only the rock half remains. E. B. B.

Fluvio-glacial Gravels.—Fluvio-glacial gravels deposited by the melt-water of the glaciers in the form of cones, fans and terraces are found in some of the glens, generally in association with hummocky moraines. These gravels vary in character from a tumultuous assemblage of boulders, pebbles and sand, not easily distinguished from the loose and gravelly forms of the morainic drift, to well-stratified clean gravel and sand, closely resembling normal river deposits. All this is readily understood. A part of the material dumped by a glacier at its snout is deposited as moraine, some of it being more or less washed by the melt-waters ; whilst other parts, carried forward and rearranged by the escaping stream, may eventually give rise to terraces similar in every way to ordinary river terraces. With the exception of the Corran gravels, discussed below, none of the fluvio-glacial gravels of the district has been specially indicated on the map. Many small patches have not been separated from the morainic drift with which they occur, while larger stretches, such as high-level river terraces and deltaic cones, have been grouped as alluvium. Thus the flood-gravels forming the plain in Glen Coe between Clachaig Hotel and the rock-barrier below Loch Achtriochtan are shown merely as alluvium on the map, although probably deposited at the same time as the morainic drift which rests on the rock barrier and extends laterally along the hill-slope north of the loch.

At the mouth of Fionn Ghleann, tributary to Glen Coe, there is a conspicuous series of terraces, banked one above the other, and heading up to a morainic mass, which lies near the " granite " boundary where the glen contracts. These terraces appear to have been deposited as steeply sloping deltas which were successively eroded on the melting away of the ice. Even the lowest terrace, reaching close down to Achnacon, is considerably denuded by the stream, which has cut a deep channel for itself in the Leven Phyllites. H. B. M.

A fine fluvio-glacial cone descends into Glen Nevis from a terminal moraine near the foot of Allt a' Choire Dheirg.

The Corran gravels referred to above stand quite apart from the other fluvio-glacial phenomena of the district. They form a conspicuous terrace on both sides of Corran Narrows at about 75 ft above sea-level. This terrace looks extremely like a raised beach, but although well characterised in this one locality it is definitely absent elsewhere in Sheet 53 along the shores of Loch Linnhe and Loch Leven. Grant Wilson suggested that it marks the site of a lake between two glaciers, the one coming down upper Loch Linnhe, the other issuing from Loch Leven. This view has been accepted by Maufe and Peach.

It is quite probable that the water-level of the glacial lake was determined by that of the sea farther down Loch Linnhe. On this hypothesis Peach and Horne (1910, pp. 495-6) have suggested that the two largest lochs on the Corran peninsula are " kettle-holes in fluvio-glacial deposits of the 100-ft Beach ". These two lochs are quite remarkable considering their situation. James Murray (*in* Murray and Pullar 1910,2, pt. ii, p. 261) found them to be 74 ft and 43 ft deep respectively (the surface levels given by the Ordnance Survey are 14 ft and 6 ft). The names under which they are described by Murray, Peach and Horne are Lochan Eoin Mhic Alastair and Lochan na h-Eaglais. In calling them kettle-holes Peach and Horne imply that they mark the sites of great buried masses of ice which persisted during the formation of the Corran gravels, and then melted, leaving holes behind.

E. B. B.

RAISED BEACHES

In this district, as along much of the west coast, raised sea-beaches, or corresponding rock-platforms subtending a cliff, are found on both sides of Loch Linnhe and Loch Leven. The raised beaches consist of coarse and fine bedded gravel, sometimes mixed with sand, and are generally found in bays and at the mouths of streams, where they form broad flats, here and there ridged with low bars of gravel representing old storm-beaches. The rock-platforms make a continuous terrace connecting beach with beach along the coast. They vary in breadth according to the exposure of the site, the resistance offered by the rock to erosion, and the steepness of the slope into which the platform and cliff are cut.

This natural terrace, being the easiest route to follow, has determined the line of most of the main roads. Even where the hills rise abruptly from the sea there is a terrace sufficiently broad to carry a road, or at least to reduce the necessity for rock-cuttings to insignificance.

In neighbouring districts beyond the limits of Sheet 53 it is common to find two or three sea-margins at different heights, but one of these generally known as the " Twenty-Five-Foot Beach " is almost always more strongly developed than the others. In this district there is one well-developed sea-margin, corresponding as we shall see to the " Twenty-Five-Foot Beach," and some evidence for a lower beach in a few places, but nowhere is there undoubted evidence of the shore-line of the " Hundred-Foot Beach," or indeed of any sea-margin above the level of the so-called " Twenty-Five-Foot Beach ".

"Hundred-Foot Beach".—In spite of the great development of the gravels of this beach about the mouth of Loch Etive, only a few miles to the south, no corresponding terraces either of accumulation or of erosion have been recognised within Sheet 53. It is perhaps not surprising that such terraces are not preserved on many parts of the coast where the hills rise sharply from the sea, but it is noteworthy that, in the low, open ground, which lies north-east of Fort William, there is no trace of a shore-line above the limits of the " Twenty-Five-Foot Beach ". This low ground is covered with hummocks of loose morainic drift, which would certainly show signs of re-arrangement, if it had ever been acted on by the sea.

Although the shore-line of the beach is not recognisable, what may be its sublittoral deposits are represented by green clays. One of these deposits, according to Gwyn Jeffreys (1863) contains a marine fauna, characterised by a great number of boreal forms, which is not unlike that of the " Clyde Beds ". This claybed, but not the layer containing shells, is exposed at the bridge half-a-mile south of Fort William pier. The section when examined showed 4 ft of green clay, laminated with silt seams, and containing a few pebbles of red granite and local schists. The gravel of the " Twenty-Five-Foot Beach " overlies it.

Other green clays, which may belong to this period, are found at Cilmalieu and Glengalmadale, on the western border of the map. A short distance above the mouth of the stream at Cilmalieu, about 10 ft of stiff greenish clay is overlain by river-gravel, and in a roadside section, about 400 yd south of the house, a similar green clay, 3 ft in thickness, is overlain by gravel of the " Twenty-Five-Foot Beach," 4 ft in thickness. Just below Glengalmadale Bridge the gravel of the " Twenty-Five-Foot Beach " overlies a thin bed of peat which in turn rests on a stiff green clay in which the plate of a large *Balanus* was found. These clays rise not more than 16 ft above present high tide-mark, and were it not for the thin layer of peat one might think that they belonged to the " Twenty-Five-Foot Beach " period ; but it is evident that they are older.

The relation of the " Hundred-Foot Beach " to the morainic drift is perplexing. In this district and in Loch Eil the latter comes down to the " Twenty-Five-Foot Beach " where it is eroded and its material re-arranged to form beach-gravels. The absence of the shore-line of the " Hundred-Foot Beach " at once raises the question whether in this district the morainic drift is contemporaneous with or later than the " Hundred-Foot Beach".

If the Fort William clay with its boreal shells belongs properly to the " Hundred-Foot Beach" period, it must be looked upon as a relic which has escaped erosion during an advance of the glaciers responsible for the moraines. We should have to suppose : that the sea of the " Hundred-Foot Beach " extended up Loch Linnhe at least as far as Fort William ; that the glaciers which formed the morainic drift increased again and reached down Loch Linnhe beyond the limits of Sheet 53, sweeping out most of the deposits of the "Hundred-Foot Beach"; and that the sea-level was lowered before the ice had again retreated very far. It must be admitted that this suggestion does not rest on a very sure foundation, but it is in keeping with the relations subsisting between the morainic drift and the " Hundred-Foot Beach " in other parts of the Highlands, for instance in south-east Mull and at Loch Lomond.

" Twenty-Five-Foot Beach ".—This beach and its associated rock-notch form a well-marked feature along the shores of Loch Linnhe and Loch Leven. The deposits consist of more or less well-rolled gravel and sand, sometimes as much as 15 ft in thickness. The pebbles in the gravel consist of local rocks mixed with far-travelled stones derived from the neighbouring drifts. From its position and from the size of many of its boulders Grant Wilson concluded that the spread of raised beach north of Ballachulish Ferry is in large measure a resorted moraine. No fossils have been recorded from the gravels of Sheet 53, though Gwyn Jeffreys says that the beach overlying the fossiliferous clay at Fort William contained littoral species and shells which must have been thrown up by the tide.

In two instances the gravels rest on peat layers. In one of these, already mentioned, the raised-beach gravels just below Glengalmadale Bridge on the western margin of the map are separated by a thin layer of peat from underlying green clay. In the other, coarse stratified gravel and sand, about 15 ft in thickness, on the right bank of the River Lochy (Sheet 62, Geol.), a mile and a half north of Fort William, and 1000 yd west of the Lochy Suspension Bridge, rest on a bed of sandy peat containing prostrate tree-trunks up to 1 ft in diameter. The mosses in the peat-bed have been examined by H. N. Dixon (1910), who found nearly forty species, and showed that the conditions under which these grew indicate " a stream of some magnitude—not a mere rivulet—tumbling over boulders, and flowing, at times at any rate between wet rocky cliffs, down a wooded mountain side or valley ". He further concludes that the flora is " indicative of a mild and equable climate," and believes " its presence may be taken as fairly conclusive that the climate of the period was at least in no degree more boreal than at the present time ". The presence of the peat shows further that the sea-level before " Twenty-Five-Foot Beach " times was lower than it is at the present day ; that is to say, the lowering of sea-level from " Hundred-Foot Beach " times to the present day was not a simple lowering accompanied by halts, but was interrupted by at least one oscillation of appreciable magnitude.

The altitude of the shore-line of the " Twenty-Five-Foot Beach " is in this district always above the 25-ft contour line. The beach has, in fact, sometimes been called the " Fifty-Foot Beach". The inner angle of the rock-shelf lies at about 35 ft above O.D. H. B. M.

PEAT AND ALLUVIUM

Peat is widely developed, but in subordinate amount. It is constantly found in the hollows between moraines, and is a very valuable source of fuel for the crofters and gamekeepers.

The most important moss is situated on the gravel flats at Clovulin, south-west of Corran Narrows.

There are considerable stretches of alluvium in several of the main valleys, notably Glen Gour, Glen Coe, Glen Creran and Glen Etive. As pointed out already, it has not been found possible to distinguish with precision between normal alluvium and fluvio-glacial gravels.

Some of the alluvium has accumulated in lochs. At the present day Loch Achtriochtan, Glen Coe, is obviously in process of extinction. E. B. B.

CHAPTER XXIII

ECONOMIC GEOLOGY

THE district is one of the most rugged in Scotland, and consists for the most part of mountain and high moorland. The higher ground is mostly deer forest but also provides rough grazing for sheep ; cattle are grazed on the lower slopes and in the valleys. There is no concentration of arable land, but many of the discontinuous patches of raised beach have been brought under cultivation. After the removal of the old Caledonian Forest, which originally extended over much of the district, timber was nowhere grown on a commercial scale for many years. Since 1920, however, planting of coniferous trees has been proceeding, mainly on the eastern side of Loch Linnhe, where for instance the Forestry Commission has considerable plantations in the Glen Nevis, Onich and Duror areas.

Owing to its western situation and mountainous topography, the area receives an abundant rainfall. Water supplies for houses and for the centres of population are almost entirely derived from surface sources such as springs, streams and small reservoirs. The exploitation of the water power resources of the district has led, during the present century, to the development of an important mineral industry, the manufacture of aluminium, first at Kinlochleven (1909) and then at Fort William (1929). The raw materials are imported, but the availability of a very considerable head of water for the generation of electricity is, as discussed in chapter i, related to the late geological history of the area. The Blackwater Reservoir, for instance, which supplies the Kinlochleven factory, lies at a height of about 1000 ft above O.D., in a remnant of one of the eastward-draining consequent valleys (Fig. 1) which were incised in relation to a sea considerably further away than Loch Leven and Loch Linnhe are today. Adjustment accompanied development of subsequent valleys guided by structural features—in this case the Loch Leven shatter-belt—and resulted in the segmentation of the older drainage system and the beheading of its streams. The remnants of the consequent valleys are thus in some cases left " hanging " in relation to the subsequent valleys as later modified by glaciation ; and it is this characteristic, combined with the high rainfall, that has made possible the development of hydro-electric power in the district. The water power resources have not yet been fully tapped, and a project is now under consideration to divert by tunnel the waters of upper Glen Nevis in order to produce power on the shores of Loch Leven (Rep. N. Scot. Hydro-Elect. Bd. for 1954).

Various mineral industries have developed from time to time in the district, largely as a result of the proximity of the raw materials to the coast and of the availability of cheap transport by sea. Slate, granite, kentallenite, quartzite, limestone, dolomite and phyllite have all been quarried, the slate on a large scale, the other rocks to a lesser extent. Peat has long provided a local source of fuel. Road metal of reasonably good quality is readily obtainable in most parts, and the materials used have included granite, porphyrite, andesite, quartzite, etc., as well as gravel from raised beach and morainic deposits.

SLATE

The Ballachulish Slates were until fairly recently quarried on a large scale for the manufacture of roofing slates. Work was begun at Ballachulish about 1697, and during the 18th and 19th centuries the excellent quality of the slate and the large quantities that were produced placed Ballachulish in the forefront of the Scottish slate industry. Between 1837 and 1869 the annual output increased from 3 million slates to 15 million, and the quarries in the latter year gave employment to 400 men. In 1937 production was 4½ million slates, about 200 men being then employed. After a decline in the industry during the second world war an attempt was made to resuscitate it in the immediate post-war period. The revival was however short-lived and the quarries are no longer in operation.

The workable slates of the district all belong to the Ballachulish Slate group, the extensive outcrops of which belong to the cores of the Appin and Ballachulish recumbent synclines. In the Ballachulish Core the principal slate outcrop is that which extends for about 6 miles south-south-westwards from its western outcrop on the two shores of Loch Leven, at Callert and Ballachulish (Fig. 8 and Pl. III, pp. 50, 55). Only the northern part of this belt is of economic interest and it is here that the industry found its greatest development. The slate has been worked in five quarries of varying size, all south of Loch Leven. The largest is the Main (Ballachulish) Quarry at East Laroch, roughly 400 yd long and 280 yd wide. It has been worked into the hillside along a number of galleries ; and the height of the quarry face is some 300 ft above floor-level, from which extensive sinkings reach an additional depth of about 115 ft. Five seams of especially good quality are known in this quarry and from these the bulk of commercial slate was derived. The method of working is briefly described in the 1916 edition of this memoir (pp. 230-1). Reserves of good quality slate-rock in the Ballachulish area are very great, and there is ample scope both for the extension of existing workings and for new development.

The slates which constitute a large part of the Appin Core north of Loch Leven extend north-eastwards in a wide belt for over 7 miles, from North Ballachulish almost to Glen Nevis. There are immense resources of slate-rock in this belt, but apart from a number of trial pits and a fairly large quarry at North Ballachulish there has been no attempt to exploit them. In the North Ballachulish Quarry pyrites has been altered to pyrrhotite by the Ballachulish " Granite " across the loch, and this weathers freely to give holes (p. 38). Much of the slate outcrop is difficult of access, and the most promising area for future development appears to be in the vicinity of the existing quarry, which is adjacent to both main road and sea-loch ; but it would have to be far enough inland to escape the effect of the " granite ". Another possibility is in Gleann Righ, about 1½ miles to the north-east.

The slate-rock is fine-grained, and dark grey or bluish grey—generally called black ; the cleavage faces, though even, often show a well-marked " grain " or lineation. Pyrites is abundant, usually in scattered cubes one sixteenth to one quarter of an inch across. The presence of pyrites does not however adversely affect the lasting qualities of the slate (except at North Ballachulish), for this mineral has proved to be very stable even in a town atmosphere ; nor does it interfere with the regular cleavage of the slate as the crystals usually break across when the slate is split, leaving a flat surface. The rock splits along a true slaty cleavage which is determined by a parallel orientation of the minute mineral constituents. The bedding is obscure in the best of the slates, but may be indicated by parallel banding where the normal slate contains limy or siliceous intercalations ; it may coincide with the cleavage, but frequently is greatly folded and puckered, with the cleavage running parallel to the axial planes of the minor folds. Where the cleavage is even, the slate-rock splits easily. In some areas, however, *e.g.* the strip of Ballachulish Slates east of Ballachulish, at the entrance to Glen Coe, the cleavage is so badly puckered that the slate is unworkable.

As much of the slate-rock is unsuitable for the production of roofing slates, the latter have constituted only a small proportion of the rock actually quarried, and large quantities of waste slate have accumulated. While this material has been employed locally for building and other purposes no systematic attempt has been made to put it to more profitable use. Elsewhere, powdered slate has found application in many industrial fields (Jones 1921). It has been used, for instance, in the manufacture of bricks and tiles, in the glass and pottery industries, as a filler in the manufacture of coarse rubber wares, and as a base for paints and distempers. The Ballachulish Slate is of suitable composition for cement manufacture (Robertson, Simpson, and Anderson 1949, p. 16), and the utilisation of crushed waste for this purpose would be facilitated by the availability of limestone in the district. When heated to a temperature high enough to cause surface fusion, some slates expand considerably, giving a product which can be used as a lightweight concrete aggregate (Lea 1956, p. 501) ; it is possible that slate waste from the Ballachulish quarries might be suitable for this purpose.

Further References.—Bremner 1869, pp. 429-32. Carmichael 1837, pp. 400-2. M'Gregor 1845, pp. 247-51. Richey and Anderson 1944, pp. 2-13, 32-4. (References expanded p. 289).

" GRANITE "

Ballachulish.—The only " granite," that is, granite or quartz-diorite in the geological sense, which has been worked in the district for other than local use is the Ballachulish " Granite ". This has the advantage of a sea frontage some 2½ miles long between Ballachulish Ferry and Kentallen (5 of Fig. 18, p. 129). In the bluff behind the narrow raised-beach platform a number of quarries have been opened in the quartz-diorite which forms the outer member of the complex. The rock in this area is grey and of an even, medium texture, but the presence of numerous dark inclusions of baked schist detracts from its appearance. It was at one time largely used as a building stone in Oban and elsewhere in Argyllshire, but all the quarries have now been abandoned owing to the capricious nature of the jointing. The jointing and inclusions do not, however, affect the quality of the rock as roadstone or as material for concrete aggregate, for which working might be resumed.

The pink granite which forms the central part of the complex is in general free of inclusions, but is nowhere easily accessible, since its outcrop lies for the most part above the 1500-ft contour. A narrow band of " white granite," also free of inclusions, occurs in a small outcrop of quartzite about 1¾ miles north-east of Kentallen. In a small trial quarry this " granite " was found to be too irregularly jointed for the extraction of sizeable blocks ; it might however be used for setts or roadstone.

Mullach nan Coirean.—The northern extremity of the Mullach nan Coirean Granite (2 of Fig. 18) is exposed in Glen Nevis, between five and six miles from Fort William, from which it is accessible by road. The rock is a pink, rather coarse granite and is moderately widely jointed. It has been quarried from time to time, for example, for a bank in Fort William and more recently for a new bridge over the Nevis.

Ben Nevis.—The various members of the Ben Nevis Complex (1 of Fig. 18) outcrop for the most part in rugged and relatively inaccessible ground. The porphyritic Subzone 4 of the Outer " Granite " and the coarse, grey non-porphyritic quartz-diorite (Subzone 3), which is the main component of the marginal intrusions on the west side of the complex, are, however, reasonably accessible on the east side of Glen Nevis (Fig. 31, p. 178). As both rocks are fairly widely jointed and are free from inclusions and aplite veins they might repay working in this area. The porphyritic Outer Granite is a handsome rock, not unlike Shap Granite, and might find a use as an ornamental stone. Ben Nevis " granite " was used in concrete aggregates for the Lochaber Water Power Scheme.

Other Granites.—The Moor of Rannoch and Etive " granite " complexes (7, 8 of Fig. 18) extend into Sheet 53, but because of their position are not likely to be of economic interest in this area. The Fault-Intrusion of Glen Coe (6 of Fig. 18) has been quarried on a small scale at Clachaig. The granites which outcrop along the west coast of Loch Linnhe (3, 4 of Fig. 18) are for the most part crushed and brecciated as a result of movement along the Great Glen Fault and are therefore of no economic value, except, possibly, for road metal.

Reference.—Anderson and Macgregor 1939, pp. 44-53.

KENTALLENITE

Kentallenite, locally known as " black granite," was at one time quarried at the type locality of Kentallen. A handsome dark rock with large, lustrous biotites, it takes a good polish and was formerly in demand as a monumental and ornamental stone. The quarry was abandoned when the construction of the branch railway to Ballachulish prevented further extension into the hill behind ; but new quarries could easily be started or the abandoned quarry deepened.

The Kentallen and other outcrops of dark igneous rocks (appinite, augite-diorite, cortlandtite, kentallenite, monzonite) are shown in Fig. 32, p. 186. With the exception of the Kentallen stone none of them has been exploited.

QUARTZITE

Appin Quartzite.—South of Loch Leven the Appin Quartzite outcrops in a broad belt between Kentallen and Appin. It was formerly quarried on the hillside above Lagnaha, south of Kentallen, for export to the English pottery district, where it was used in the form of setts to pave the grinding tubs and as runners driven forward over the floor of the tubs by revolving vanes. It is felspathic, and is said to maintain a rough surface suitable for grinding purposes better when slightly weathered than when it is quarried at some depth. From its connection with the pottery industry the quartzite came to be known locally as " china-stone ". The Lagnaha rock has also been used for grinding with pottery clay, as refractory cylinder linings and as a constituent of scouring soap.

North of Loch Leven, the quartzite forms an extensive outcrop in the Onich area. Although the Appin Quartzite invariably contains a certain amount of felspar, it is locally a fairly pure silica-rock. In a cutting along the main road about a mile east of Onich Pier some 300 ft of intensely white quartzite are exposed ; a rough estimate places its silica content at about 95 per cent. The reserves are very great and the locality is well placed for road or sea transport.

Binnein Quartzite.—The Binnein Quartzite, BQ of Fig. 15, p. 99, is the only quartzite in the district which is sufficiently free from felspar and other impurities to merit consideration as a possible source of high-grade silica-rock for the manufacture of refractories, etc. It outcrops on both sides of Loch Leven at Caolasnacon, and in the Kinlochleven area where it forms a belt about 2½ miles in width interrupted by an irregular outcrop of Binnein Schist. It frequently has a rusty appearance owing to the presence, both in the rock itself and as a coating along joint planes, of iron oxide. In its purest form, however, it is a glittering white, fine to medium-grained rock with very even texture ; felspar is not noticeable in the hand-specimen, but a few tiny muscovite flakes are sometimes apparent. On analysis, bulk samples from a number of localities both north and south of Loch Leven showed a silica content ranging from 97·80 to 99·10 per cent. The reserves of Binnein Quartzite are immense and the rock could easily be quarried within convenient reach of road or sea transport.

Imperial Chemical Industries Ltd. has kindly informed us that quartzite in lump form, obtained from the Caolasnacon outcrop south of Loch Leven, has recently been used, on account of its high purity, to fill an absorption tower in a sulphuric acid plant in Glasgow.

References.—Anderson 1945a, pp. 7-10 ; analyses, pp. 21-5. Hinxman 1920, pp. 149-50, 163-4.

LIMESTONE, DOLOMITE, AND MARBLE

Limestone and Dolomite.—The district as a whole is comparatively rich in limestones, but much of the material shown on the one-inch map as limestone is no more than slightly calcareous schist of no economic value. Moreover, in the vicinity of the various " granites " the impure limestones are altered to calc-silicate-hornfelses. East of Loch Linnhe there are two, probably three, distinct limestone groups, Ballachulish, Appin and Shuna, all three quarried for local purposes. The Ballachulish Limestone provides fairly extensive outcrops of high-grade non-dolomitic limestone (as for instance at Creag Aoil Quarry) in the area north-east of Fort William, beyond the northern limit of Sheet 53 ; it is, however, of limited economic importance in the present district, as bands of reasonably pure material are uncommon and are of restricted extent.

The Appin Limestone, formerly quarried at Onich and Duror for agricultural purposes, is dolomitic in character. Both in regard to its magnesia content and its purity it shows a wide range of variation, but locally it approaches the composition of a true dolomite (Analyses, p. 244). A highly dolomitic band extends south-westwards from Acharra House, Duror, to Portnacroish (Appin railway station). The best quality of dolomite so far found within the Appin Limestone outcrop occurs in this band in the Duror area. Its silica content, however, varies considerably, and sometimes reaches a high proportion ; the rock therefore cannot be considered either for refractory purposes or for magnesium production. The reserves are probably considerable and the area is within easy reach of road and rail transport. In recent years dolomite from the Duror area has been utilised by The Cape Asbestos Co., Ltd., Rocksil Works, Stirling, for the manufacture of rock-wool, a material which finds increasing application in thermal and sound insulation. The company concerned has kindly supplied the following details of its use. The dolomite, after preliminary crushing at the quarry, which has an annual output of several thousand tons, is conveyed to Stirling, where it is powdered, mixed with a certain proportion of fireclay, and briquetted. The briquetted material is melted at approximately 1500°C and the molten matter extruded into fine filaments which are collected on a conveyor belt to make a fleecy mass of fine, interlacing fibres of rock-glass. This material is marketed for loose-fill insulation and, in conjunction with various bonding agents, also forms the basis of a wide range of insulating products including slabs and quilts of various types, many of which can be cut and shaped as required.

Part of the Appin Limestone outcrop in the Ballachulish area consists of dolomite of fairly high quality. At one locality in Gleann an Fhiodh (p. 60), the rock is very friable and falls readily into a fine powder which has excellent abrasive and polishing qualities.

Marble.—At the " Marble Quarry," close to the last-mentioned locality, another band of the Appin Limestone is of the " tiger-rock " variety, cream and pale pink in colour, with dark grey stripes. An attempt was made to exploit this rock as an ornamental stone, but in spite of its handsome appearance it did not find a market. The sparkling white appearance of much of the Duror outcrop of Appin Limestone makes it highly suitable for terrazzo chippings, ornamental stone dressings, etc., where a light-reflecting surface is desired ; the rock might also be of value as an ornamental stone, particularly where it contains streaks of green serpentine.

Several bands of white crystalline marble occur in association with rocks of the Glen Scaddle igneous complex of chapter ix. There is no record of their having been worked and they are probably not sufficiently accessible to be of economic interest.

Brucite-marble, a material which has been successfully used in America as a substitute for magnesite in the manufacture of basic refractory linings, is developed where the dolomitic Appin Limestone comes in contact with the Ballachulish " Granite ". The most easily accessible locality is near Kentallen, but the material there is of rather inferior quality.

References.—Anderson 1945b, pp. 3-5, 13-4 ; analyses, pp. 16-20. Anon. 1954, pp. 16-7. Guppy and Phemister 1949. Hinxman 1920, pp. 224-5. Kennedy 1940, pp. 7-10. Muir and others 1956 ; analyses, pp. 20, 80. Robertson and others 1949, pp. 16-8, 21, 36, 49-52, 56, 112. Wilson and Phemister 1946, p. 7.

PHYLLITE (FOR BUILDING)

On the north side of Loch Leven, east of North Ballachulish, the Leven Schists were at one time quarried fairly extensively for building stone. The cleavage here is even and unpuckered, and the rock can be readily worked in large slabs.

MINERAL VEINS, ETC.

Barytes.—A vein of barytes, stated in the 1916 edition of this memoir (p. 234) to be 4 ft thick, occurs in a steep gully leading to the Allt a' Gharbh Choire Bhig, a tributary of the Amhainn Coir' an Iubhair. The locality is about 1400 yd E. 10°S. of the summit of Garbh Bheinn (Ardgour). Further examination of the occurrence, by K. C. Dunham in 1946, shows that the barytes, 1 ft in average thickness, occurs on the hanging wall side of a mineralised crush-breccia associated with a north-west basic dyke which has been traced for many miles (p. 263). The breccia, about 3 ft thick, consists of fragments of dyke and country rock in a matrix of chalcedonic silica, white carbonate, and, locally, quartz ; it contains a very little barytes. The well mineralised zone extends for about 80 yd in an east-south-easterly direction from the point where the dyke gives off three branches (two of which are indicated on the one-inch map). Evidence of strong chalcedony-carbonate mineralisation with a little barytes was also found further to the east-south-east along the course of the dyke.

Galena.—Galena occurs in a small calcite vein in limestone near Invercreran, Glen Creran. An early attempt to work it proved unsuccessful (Wilson 1921, p. 92). A small amount of galena is associated with the barytes of the Ardgour occurrence described above.

Haematite.—A haematite vein has been mapped between 1400 and 1500 yd E. 17° N. of Glen Ure House. There is no record of its thickness, but it may have been worked at one time, since charcoal, probably the relic of a local bloomery, was found nearby.

Pyrites.—The Ballachulish Slates might possibly be of economic interest as a source of pyrites, particularly if the large quantities of slate debris from the quarries were to be utilised, for instance, in cement maufacture. The mineral forms conspicuous cubes, usually from one sixteenth to a quarter of an inch across, but occasionally up to an inch or more. The quantity of pyrites in the waste heaps must be considerable, and a useful tonnage might be obtained by concentration after crushing the slate debris.

Sand and Gravel

Spreads of alluvial and fluvio-glacial sand and gravel flank many of the streams and rivers, and there are frequently considerable areas of raised beach deposits at river mouths (*e.g.* Invercoe and Inverscaddle), and in bays (*e.g.* at Onich and North Ballachulish). On both sides of the Corran Narrows, but particularly on the west, there are wide expanses of fluvio-glacial sand and gravel which form a terrace at about 75 ft above sea-level. Locally the morainic drift of the district consists of rudely bedded sand and gravel. None of these deposits appears to have been worked for more than intermittent local use.

Peat

Although large spreads are uncommon, peat is widely distributed throughout the area and for long has provided a local source of fuel. The most important moss, which has been extensively worked, is situated on the gravel terrace at Clovulin, south-west of the Corran Narrows. T. R. M. L.

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